This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.

+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.

+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.

+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`

Init: notice

VGS

Internati

v. G

A TEXTBOOK

ON

ELECTRIC LIGHTING AND RAILWAYS

INTERNATIONAL CORRESPONDENCE SCHOOLS
SCRANTON, PA.

ELECTRIC LIGHTING
INTERIOR WIRING

[illegible]

SCRANTON
INTERNATIONAL TEXTBOOK COMPANY
B–2

THE NEW YORK
PUBLIC LIBRARY
548438
ASTOR, LENOX AND
TILDEN FOUNDATIONS
1913

Copyright, 1901, by INTERNATIONAL TEXTBOOK COMPANY.

Entered at Stationers' Hall, London.

Electric Lighting: Copyright, 1901, by INTERNATIONAL TEXTBOOK COMPANY.
Entered at Stationers' Hall, London.
Interior Wiring: Copyright, 1901, by INTERNATIONAL TEXTBOOK COMPANY.
Entered at Stationers' Hall, London.

All rights reserved.

cIII
BURR PRINTING HOUSE,
FRANKFORT AND JACOB STREETS,
NEW YORK.

CONTENTS.

ELECTRIC LIGHTING.

	Section.	*Page.*
Incandescent Lighting	16	3
The Incandescent Lamp	16	3
Measurements and Lamp Calculations	16	13
Properties of Incandescent Lamps	16	25
Methods of Connecting Lamps	16	37
Systems of Distribution	16	41
Line Calculations	16	69
The Lighting Station	16	79
Dynamos for Incandescent Lighting	16	81
Station Appliances	17	1
Switches and Bus-Bars	17	1
Ammeters and Voltmeters	17	9
Fuses and Circuit-Breakers	17	24
Rheostats	17	30
Ground Detectors	17	33
Lightning Arresters	17	41
Switchboards	17	50
Potential Regulators	17	64
Use of Storage Batteries in Lighting Plants	17	68
Arc Lighting	18	1
The Arc	18	1
Enclosed Arcs	18	6
Arc-Light Carbons	18	11
Photometry of the Arc Lamp	18	15
Candlepower of Arc Lamps	18	21

ELECTRIC LIGHTING—*Continued.*

	Section.	*Page*
Methods of Distribution	18	26
Arc Lamps	18	36
Examples of Arc Lamps	18	42
Constant-Potential Arc Lamps	18	66
Care and Adjustment of Arc Lamps	18	72
Line Work for Arc Lighting	18	77
Special Applications of Arc Lamps	18	89
Testing Arc-Light Lines	19	1
Lightning Protection for Arc Circuits	19	7
Station Equipment	19	10
Constant-Current Arc-Light Dynamos	19	11
Care of Arc Machines	19	28
Alternating-Current Arc-Light Dynamos	19	35
Operation of Series Arc Lamps from Constant-Potential Alternators	19	37
Arc-Light Switchboards	19	44

INTERIOR WIRING.

Preliminary Considerations	26	1
Fires Caused by Electric Wiring	26	2
The National Electrical Code	26	2
Examples of Electrical Fires	26	4
Electric Lamps	26	10
General Rules	26	18
Wiring for Low-Potential Systems	26	24
Systems of Distribution for Interior Wiring	26	27
Switches and Cut-Outs	26	34
Open Work in Dry Places	26	40
Wiring for a Uniform Drop	26	56
Calculation of Line Losses Due to Resistance	26	59
Calculation of the Proper Size of Wire for a Given Loss	26	62
Effect of Connecting Low-Voltage Current and Lamps to Wiring Calculated for High Voltage	26	66

INTERIOR WIRING—*Continued.* *Section.* *Page.*

Uniform Drop in Feeder Lines . . . 27 1
Calculation of Wires in Terms of Circular Mils 27 5
Forms of Wiring Tables 27 9
Fuse Protection for Conductors in Multiple 27 14
Wiring in Damp Places 27 18
Concealed Knob-and-Tube Work . . . 27 21
Wiring a Dwelling House 27 30
Fixtures 27 44
Location and Distribution of Lamps . 27 47
Conduit Wiring 27 49
Wooden Moldings 27 63
Tests 27 65
Marine Work 27 68
Wiring Estimates 27 72
Combining Several Wiring Systems . . 28 1
Theater Wiring 28 4
Wiring for Special Purposes 28 6
High-Potential Systems 28 11
Wiring for Arc Lamps 28 14
Wiring for Electric Motors 28 21
Bell Wiring 28 24
Burglar Alarms 28 40
Electric Gas Lighting 28 43

EXAMINATION QUESTIONS. *Section.*

Electric Lighting, Part 1 16
Electric Lighting, Part 2 17
Electric Lighting, Part 3 18
Electric Lighting, Part 4 19
Interior Wiring, Part 1 26
Interior Wiring, Part 2 27
Interior Wiring, Part 3 28

ANSWERS TO EXAMINATION QUESTIONS. *Section.*

Electric Lighting, Part 1 16
Electric Lighting, Part 2 17

ANSWERS TO EXAMINATION QUESTIONS—
Continued.

Section.
Electric Lighting, Part 3 18
Electric Lighting, Part 4 19
Interior Wiring, Part 1 26
Interior Wiring, Part 2 27
Interior Wiring, Part 3 28

ELECTRIC LIGHTING.

(PART 1.)

INTRODUCTORY.

1. The subject of electric lighting involves a consideration of the different methods used for carrying out artificial illumination by means of electrical energy. This means that not only must the actual means of converting the electrical energy into light be considered, but that the methods used for its generation and distribution must also be given due attention.

2. There are, in general, two methods in common use for producing light by means of electricity: (*a*) By means of incandescent lamps; and (*b*) by means of arc lamps.

Both of these methods are extensively used, the arc light being especially adapted for street lighting, although it is largely used for interior lighting as well. The principal field for incandescent lighting is interior illumination, but incandescent lamps are also used for street lighting, especially in places where the streets are thickly shaded by trees, or in cases where a fairly uniform distribution of light is desired.

3. In the incandescent electric lamp, light is produced by bringing a continuous conductor of high resistance to a very high temperature by passing a current through it. If a current is sent through a conductor, there will be a certain loss of energy in the conductor due to the resistance that the current encounters in flowing through it, and this loss reappears in the form of heat. In the incandescent lamp,

For notice of the copyright, see page immediately following the title page.

service with old or cheap lamps that soon run down in candlepower. Central-station managers are coming to realize this point more than was once the case and are devoting more attention to the quality of the lamps that they buy; in fact, most progressive companies now provide means for testing their lamps.

CONSTRUCTION OF LAMPS.

8. Early Experiments.—It was not long after the invention of the arc lamp until inventors turned their attention to the production of electric light by heating continuous conductors to a high temperature by means of the current, instead of using the arc, because the early forms of arc lamps were not well suited to interior illumination. The first experiments were made with platinum or iridium wire. These wires were mounted in the open air and current sent through them, the current bringing the wire to a white heat and thus causing light to be given off. All these lamps proved failures because the wire very soon burned out. The temperature to which it had to be raised was very near the melting point of the metal, and if great care were not exercised the wire would fuse. In later experiments, the wire was enclosed in a glass globe from which the air was exhausted. This was a great step in advance, because it prevented the conductor from becoming oxidized and thus destroyed by the action of the air; it also prevented the wire cooling off so fast, and thus allowed the high temperature to be maintained by a much smaller current than would be required were the wire heated in the open air. Even when the platinum or iridium wire was enclosed in a globe from which the air had been exhausted, it was found that, although the lamps were very much improved, they were not suitable for commercial use. It became evident that some substance that would be cheaper and capable of standing a higher temperature would be necessary. Carbon was finally selected as the substance most suitable and is now universally used.

9. There has been considerable discussion as to who invented the incandescent lamp, and the probabilities are that its invention was not due to any one person. Edison tried a great many experiments to determine the best substance for the conductor, or **filament,** as it is usually called. The material that he finally selected was bamboo fiber, which was cut to the proper size and then carbonized. Maxim made lamps with filaments of carbonized paper. These lamps embodied all the essential parts contained in the modern lamp shown in Fig. 1, but lamps as now made are very much improved in efficiency and are decidedly cheaper. The work of Edison undoubtedly first placed the incandescent lamp on a commercial basis.

10. Filaments.—As mentioned before, bamboo was used at one time for the construction of lamp filaments. Fig. 2 shows the general shape of one of these early bamboo filaments. The ends *a*, *a* were enlarged so that the heating at the joint between the leading-in wires and the filament would be much less than that of the filament proper. Lamp filaments as now made are usually in the forms shown in Fig. 3 (*a*), (*b*), and (*c*). (*a*) is the plain loop filament, (*b*) the spiral, and (*c*) the oval. In Fig. 3 (*c*), the filament is fastened at *x* to a small platinum wire fused into the glass, and is spoken of as an **anchored filament.** This is done to prevent violent vibrations of the filament, which would tend

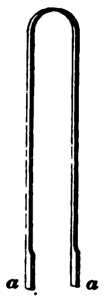


FIG. 2.

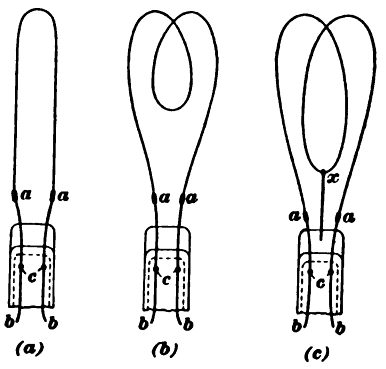


FIG. 3.

to shorten the life of the lamp, and lamps of this type should be used in any place where they are subjected to vibration, as, for example, on street cars. Filaments have been made of carbonized silk or cotton, but the more common method of manufacture at present is by what is known as the squirting process. This process consists in squirting the material, usually cellulose or a mixture of carbonaceous materials, through dies. These threads are then cut to the proper length, wound on forms to hold them to the required shape, and carbonized. This process has been found to make more uniform and very much cheaper filaments than the older methods.

With the old process of making filaments, it was necessary to treat them to what is known as the flashing process. This was necessary because the old-style filaments were not uniform in cross-section, and when used in the lamps would glow more brightly in some spots than others and soon burn out. To overcome this, the filaments were placed in a hydrocarbon vapor and current sent through them until they were brought to a red heat. The parts that were small in cross-section would become hotter than the rest of the filament, and carbon in the form of graphite would be deposited on these parts, thus bringing up their cross-section and making the filament uniform. This process is not necessary with modern filaments in order to make them uniform, but it is continued, nevertheless, because it has been found that the layer of graphitic carbon so deposited makes the lamp have a considerably higher efficiency than it would otherwise have. The layer of graphitic carbon is a much poorer radiator of heat than the body of the filament, and thus allows the temperature necessary for the emission of light to be maintained with a less expenditure of energy than would the untreated filament. It is this layer of graphitic carbon that gives the filaments their familiar steel-like appearance.

11. The size of the filament depends altogether on the candlepower of the lamp and the voltage and current with which it is to be supplied. The lamp shown in Fig. 1 is one of 16 candlepower, such as would ordinarily be used on a 110-volt circuit. Such a lamp would require about ½ ampere; hence, from Ohm's law, its resistance when hot must be in the neighborhood of 220 ohms. In order to get such a high resistance, the filament must be long and fine. Lamps designed for low voltage and large current would be provided with short, thick filaments. Fig. 4 shows a low-voltage lamp designed to take about 3½ amperes. In this case the filament is short and correspondingly thick. Lamps with thick filaments, like the one shown in Fig. 4, are not so efficient as those with long, fine filaments.

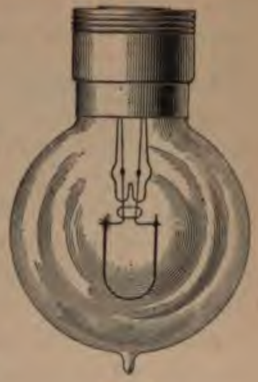


FIG. 4.

Fig. 3 shows the way in which the filaments are usually mounted. The filament is fastened to the platinum wires *a*, *a*, which are sealed into the glass and thus render the globe air-tight. The junction between the filament and the leading-in wire is effected by means of carbon paste; this paste also enlarges the cross-section of the joint, so that the heating is small compared with that which takes place in the filament itself, and the leading-in wires are, therefore, kept cool.

12. The Leading-In Wires.—These are made of platinum, because this metal has almost exactly the same coefficient of expansion as glass, and also because it does not oxidize. If the glass and platinum did not expand at the same rate when heated, cracks would form at the point where the wires are sealed into the glass. This would let in the air and the filament would soon burn out. A film of oxide on the leading-in wires would also tend to let air leak into the globe, and platinum does not oxidize. Only enough platinum is used to pass through the glass, as shown at *a*, *a*, Fig. 3. Connection is made to the base by means of small copper wires *b*, *b* fused to the platinum at *c*, *c*. In early lamps, the whole length of the leading-in wires was of platinum, but this practice has been discontinued, owing to the high price of the metal. Substitutes for platinum for the leading-in wires have been brought out from time to time, but none of them have displaced it as yet.

13. The Bulb.—The style of bulb used to enclose the filament is familiar to almost everybody. Different shapes are in use, but by far the most common is the pear-shaped bulb shown in Fig. 1. The bulbs should not be made too small, because, as the lamp burns, the filament gradually undergoes disintegration and small particles of carbon are thrown off and deposited on the globe. This causes the well-known blackening of the lamp, and if the bulb is very small this blackening is aggravated, because the surface is smaller and the deposit, for that reason, more dense.

14. Exhaustion.—Fig. 5 shows a lamp after the stem carrying the filament and the leading-in wires have been sealed into the bottom. The lamp is now ready to be exhausted. In order to accomplish this, a small glass tube with a narrow neck at *a* is sealed into the top of the bulb. This tube is connected to an air pump, and while the air is being exhausted a current is sent through the filament. This current is gradually increased as the exhaustion progresses, and, by heating the filament, drives out any air that may have been absorbed by the carbon. The operator can tell by the performance of the lamp when the proper degree of exhaustion has been reached, and seals up the bulb by melting the glass tube at the neck *a*.

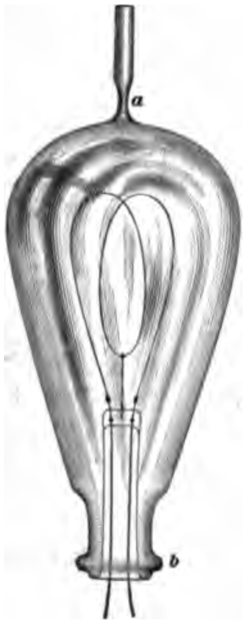


FIG. 5.

Numerous methods have been devised for the exhaustion of lamps. Ordinary mechanical air pumps, i. e., pumps that exhaust the air by the operation of a plunger in conjunction with valves, are not capable of producing a sufficiently high degree of exhaustion. They are, however, used to exhaust the greater part of the air, and the final exhaustion is then accomplished either by means of a mercurial air pump or by the chemical method.

The principle of operation of the Sprengel mercurial air pump is shown by Fig 6; $c\ d$ is a glass tube with a **T** joint at x, from which a branch tube leads to the lamp. The lower end of the tube dips below the surface of the mercury in the vessel B. Mercury is allowed to run from A by opening the pinch-cock c, and in doing so draws the air out of the bulb by carrying down a stream of air bubbles until the air is completely exhausted. When the air has become exhausted, the mercury falls from the top to the bottom of the tube with a sharp click. This style of pump is capable of producing a high degree of exhaustion, but, unfortunately, it is rather slow in its action. The pump has been modified in various ways to adapt it to commercial work, but its action is briefly as outlined above.

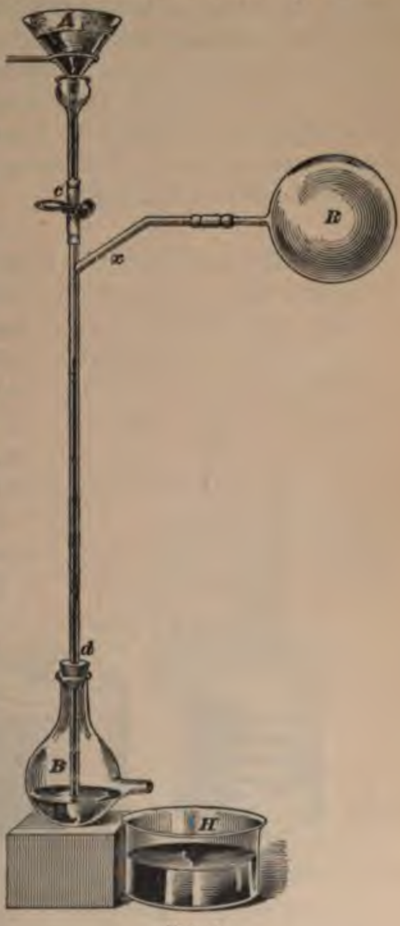
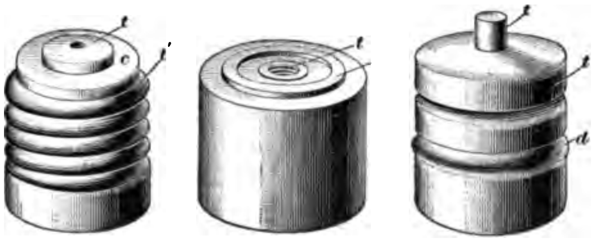


FIG. 6.

Another method of exhaustion, known as the chemical method, has recently come into use, and has rendered the process of exhaustion much more rapid. In this process, the air is first exhausted to quite a high degree by mechanical pumps. A gas is then introduced, which combines with the remaining gases and renders them incapable of acting on the filament. The process is in the main kept secret: it produces a vacuum that gives as good results as that produced by a mercurial pump, and the process is much more rapid. The chemical that is often used is phosphorus, a small quantity of which is placed in the stem of the bulb and heated when the mechanical pumps have produced the proper degree of exhaustion.

15. Bases.—After the lamp has been exhausted, it is complete with the exception of the base *N*, Fig. 1, with which it must be provided in order that it may be readily attached to the socket. These bases are usually made of brass and porcelain, the lamp being held in them by a setting of plaster of Paris or cement.

In Fig. 5, the lower part of the lamp is made of such shape that the base will be held securely when the plaster of Paris is put in place. The rib *b* prevents the base from pulling off. The base must, of course, provide two terminals for the leads from the filament, these terminals being arranged so that when the lamp is placed in the socket, contact will be made with two corresponding terminals. There are three different bases commonly used in America; these are



(a) (b) (c)

FIG. 7.

the *Edison;* the *Thomson-Houston*, or *T. H.*, as it is more commonly called; and the *Westinghouse*, or *Sawyer-Man.* These bases are shown in Fig. 7.

16. Fig. 7 (*a*) shows the **Edison base,** of which there are more in use than all the others put together. One end of the filament is attached to the outer shell *t'*, which is provided with a coarse screw thread. The other terminal is connected to the projecting center piece *t*, the two brass pieces being separated by means of a porcelain piece *c*. When the lamp is screwed into the socket, the screw shell makes one connection and the center piece the other. Fig. 8 shows a lamp screwed into an ordinary Edison key socket.

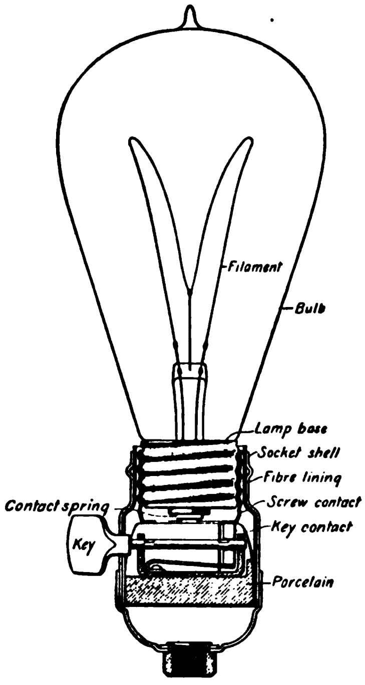


FIG. 8.

Fig. 7 (*b*) shows the **T. H. base,** so called because it was brought out by the Thomson-Houston Company. In this base, one terminal is connected to a center brass piece *t* in which a hole is drilled and tapped. The other terminal is connected to the brass ring *t'*. This base has the advantage that the outer shell, if one is used, is in no way connected to the circuit, and there is, therefore, less danger of receiving a shock by touching the lamp; it has been, and still is, used to a considerable extent, though it is gradually going out of use, as it is more expensive to make than the Edison base. It works loose in the socket a little more easily than the Edison base when the lamp is subjected to vibration. When placed in the socket, terminal *t* screws on a projecting stud, thus making one connection; the other connection is made by the ring *t'* coming into contact with a corresponding ring or terminal in the socket. The later types of T. H. base are made of porcelain with a brass center piece and outside ring, as described above.

Fig. 7 (*c*) shows the **Westinghouse base**, or the Sawyer-Man base, as it is sometimes called, because it was originally brought out by The Sawyer-Man Company. This base is similar in some respects to the Edison, but the outer shell is not threaded; the lamp is pushed into the socket, the outer shell slipping into a split bushing that is provided with an annular groove. The rib *d* slips into this groove when the lamp is in position and prevents the lamp slipping out. The other connection is made by the projecting pin *t* coming into contact with a spring in the socket. This base has the fault that it sometimes allows the lamp to drop out of the socket if the split bushing does not grip the rib *d* properly. It also makes comparatively poor contacts, which become worse with use.

17. When incandescent lamps were first brought into use on a commercial scale, each different maker had his own style of lamp base, and the result was that over a dozen different types were in use. The number has, however, been gradually reduced until the three mentioned above probably include over 95 per cent. of all the bases in use in America. The chances are that in a few years the Edison base will have replaced the others, because, taking everything into consideration, it is the best base of the three. Even plants that are equipped with sockets of other makes are fitting them with adapters so that they may be able to use Edison base lamps. Fig. 9 shows an adapter for changing T. H. sockets to take lamps with the Edison base.

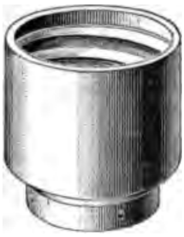


FIG. 9.

MEASUREMENTS AND LAMP CALCULATIONS.

LIGHT MEASUREMENTS.

18. Incandescent lamps are usually spoken of as giving a certain number of candlepower. For example, a lamp is spoken of as giving 16 candlepower when it produces an intensity of illumination equal to that produced by 16 standard candles.

19. The unit of brightness most commonly used is a spermaceti candle of standard dimensions. Standard candles are .9 inch in diameter at the base, .8 inch in diameter at the top, and 10 inches long; they burn 120 grains of spermaceti and wick combined per hour. Six candles weigh 1 pound. The candle is not a very satisfactory standard, as it is subject to considerable variation, and other standards have been brought out to replace the candle in practical work. Various kinds of gas and oil lamps have been used for this purpose, which, although less liable to fluctuations than the candle, have not yet superseded it.

The **Methven screen** is a convenient standard that has been used largely. This standard consists of an Argand gas burner that is provided with a screen that cuts off all the light from the flame except that of a small portion that is allowed to come through a thin-edged standard opening in the screen. The size of the opening is .233 inch wide and 1 inch long. The height of the flame is 3 inches and the screen is placed 1¼ inches from the axis of the flame. It is evident that the light given by a standard of this kind will vary considerably with the quality of the gas used, and while it may not be reliable as an absolute standard, it makes a very good working standard after its candlepower is known by comparing it with a standard candle. A slit of the above size should emit about 2 candlepower.

One of the best light standards is the **amyl-acetate** or **Hefner unit.** This lamp consists of a small reservoir provided with a wick tube of standard size. The lamp burns amyl acetate and the flame is adjusted until its tip is 40 millimeters above the top of the wick tube. This standard is very reliable and is subject to little variation. It has the disadvantage of giving a light of reddish tinge. The Hefner unit is not quite as large a unit of light as the English candle, the relation being 1 candle = 1.14 Hefner units.

For photometric tests connected with electric-light stations, neither the candle nor the amyl-acetate lamp is used as a working standard.

The general practice is to standardize either an incandescent lamp or an oil lamp by comparing it with the standard and then use the lamp so calibrated for the actual work. For example, an incandescent lamp might be carefully compared with a standard candle and its candlepower accurately determined for a given voltage. This lamp could then be used as a standard in measuring the candlepower of other lamps, provided its voltage were maintained at the correct value. A secondary standard of this kind is very much easier to work with and cheaper to operate than either a standard candle or amyl-acetate lamp. An oil lamp may also be calibrated in the same way and makes a satisfactory secondary standard for practical measurements when extreme accuracy is not required.

20. In order to determine the candlepower of an incandescent lamp, we must have some means of comparing the intensity of illumination produced by the lamp with that produced by the standard. An instrument for doing this is called a **photometer.**

21. Law of the Photometer.—Suppose that we have a candle placed at *A*, Fig. 10, and hold a screen *B* at a distance of, say, 2 feet from it. The screens are here shown bent so as to represent portions of spherical surfaces with *A* at the center.

Consider the portion of the screen *a b c d*. The intensity of illumination on the area *a b c d* will be a certain amount. Now, suppose the screen to be moved back to the position *C*, 4 feet from *A*. The total amount of light that fell on the area *a b c d* will now be distributed over the area *a' b' c' d'*. The area *a' b' c' d'* is four times that of *a b c d*, because *A m* is twice *A f* and *m h* is twice *f g* or *b' c'* is twice *b c*. The total *quantity* of light falling on the two surfaces is the same, and since the area of *a' b' c' d'* is four times that of *a b c d*, it follows that the light per unit area or the *intensity* of illumination on *a' b' c' d'* is only one-quarter that on *a b c d*. In other words, doubling the distance of the screen from the source has cut down the intensity of illumination to one-fourth its former value. If the distance *A m* were three times as great as *A f*, the intensity of illumination would be one-ninth that on *a b c d*. This law may then be stated as follows:

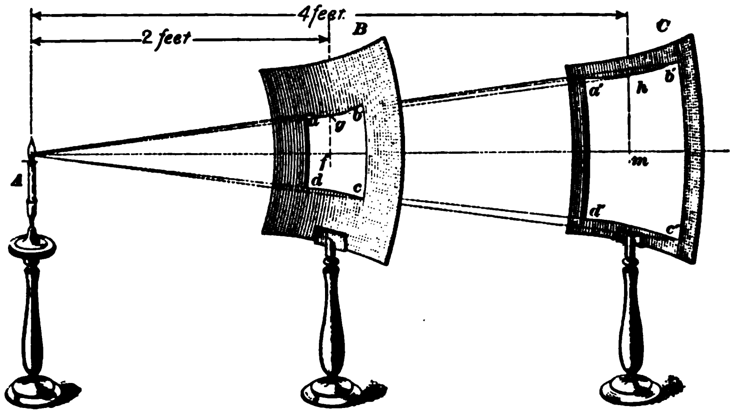


FIG. 10.

The intensity of illumination produced by a source of light on any object varies inversely as the square of the distance of the object from the source.

The word inversely is used to signify that the *greater* the distance, the *less* is the illumination. This may be also expressed as follows: If x is the illumination produced and I is the brightness of the source of light, then

$$x = \frac{I}{d^2}. \qquad (1.)$$

This means, for example, that the illumination of the surface will be doubled if the candlepower of the source is doubled and that it will be one-quarter as great if the distance from the source is doubled.

22. Elementary Photometer.—Suppose, now, that we have two sources of light, such, for example, as a candle and an incandescent lamp, and that we wish to compare the brightness of these two sources. If the candle *A* and the lamp *B* are placed in a dark room, so that there will be no other light to interfere, and a screen *C* is placed between them, as shown in Fig. 11, one side of the screen will be illuminated by the candle and the other by the lamp. If the candle and lamp were exactly of the same brightness, it is evident that the two sides of the screen would be equally illuminated when placed midway between them. If the screen is mounted so that it can be slid along between the lights, a point can always be found where the screen will be equally illuminated on both sides. In the present case, the screen would have to be moved nearer the candle than the lamp, because the candle is not as bright as the lamp. Suppose that the screen has been adjusted so that the illumination is equal on each side, and that the distances d_1 and d_2 have been read off by means of the scale *S*, d_1 being the distance from the screen to the standard candle and d_2

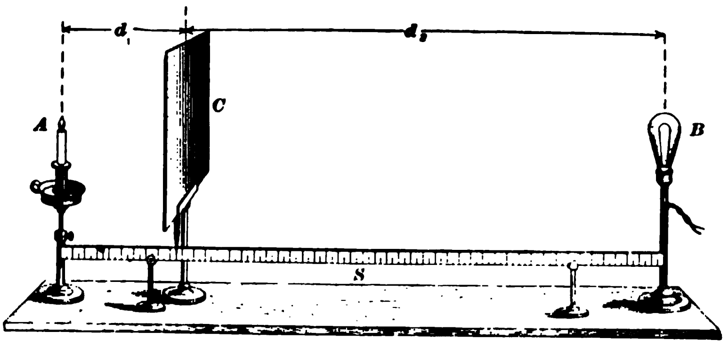


FIG. 11.

the distance from the screen to the light that is being measured.

Let x_1 be the degree of illumination produced on one side and x_2 that on the other, and I_1 and I_2 the candlepowers of the standard and the light being measured, respectively. Then from formula **1**, we have

$$x_1 = \frac{I_1}{d_1^2} \text{ and } x_2 = \frac{I_2}{d_2^2};$$

but since the illuminations on the two sides are equal, we must have

$$\frac{I_1}{d_1^2} = \frac{I_2}{d_2^2}.$$

Now, the candlepower I_1 of the standard is supposed to be known, and since the distances are also known, the candlepower I_2 of the lamp being measured can at once be calculated. For this purpose, it is more convenient to have the last equation in the form

$$I_2 = I_1 \frac{d_2^2}{d_1^2}. \qquad (2.)$$

23. The arrangement shown in Fig. 11 is a simple form of photometer, and formula **2** expresses the relation between the candlepower of the standard and that of the lamp being measured. This may be written in the form of a rule, as follows:

Rule.—*The candlepower of the lamp being tested on a photometer is found by multiplying the candlepower of the standard by the quotient obtained by dividing the square of the distance of the lamp from the screen by the square of the distance of the standard from the screen.*

EXAMPLE.—Suppose, in Fig. 11, that A is a standard candle giving 1 candlepower and that B is an incandescent lamp. The screen is moved until a point is found where the two sides are equally illuminated. The reading on the scale then shows that the distance from the standard is 20 inches. The total distance between the lamps is 100 inches. What is the candlepower of B?

SOLUTION.—If the total length of the photometer is 100 inches, the distance from the lamp to the screen must be 100 − 20 = 80 inches. The candlepower of the standard is 1; hence, substituting in formula 2,

$$I_1 = 1 \times \frac{80^2}{20^2} = 16 \text{ c. p. Ans.}$$

24. The Bunsen Photometer.—The Bunsen photometer has been more largely used than any other. It is very simple and is capable of giving good results if used properly. The arrangement of the different parts is essentially the same as that shown in Fig. 11, but the distinguishing feature of this photometer lies in the style of screen used. It would be a difficult matter to tell when a simple screen like that shown in Fig. 11 was illuminated equally on both sides, and to overcome this difficulty Prof. Bunsen devised the screen shown in Fig. 12. The screen is made by taking a piece of good quality of white paper and making a grease spot in its center, as indicated by the star in Fig. 12. If such a screen be held so that the front side is more strongly

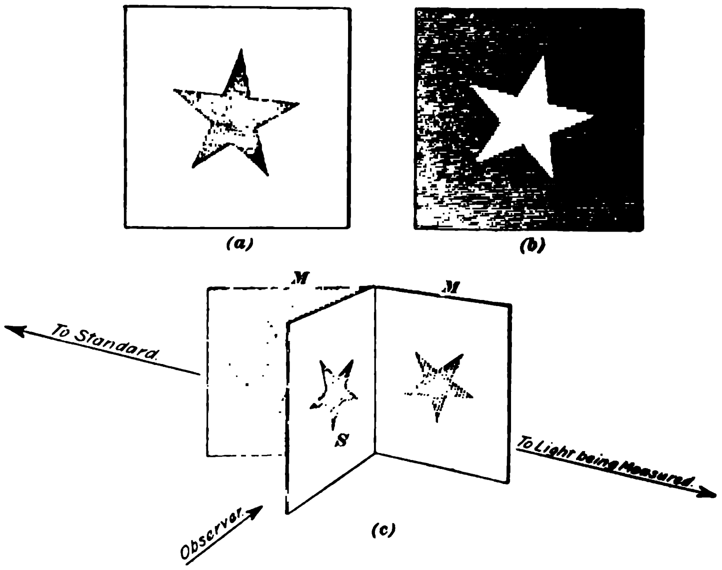


FIG. 12.

illuminated than the back side, the grease spot will appear dark on the white ground of the paper, as shown in (*a*). If, however, the screen be more brightly illuminated on the back side, as, for example, if it were held between the eye and a window, the grease spot will appear light on a dark ground, as shown in (*b*). If such a screen is mounted in place of the screen *S* in Fig. 11, and arranged so that both sides may be seen at once, the grease spot will disappear almost entirely when the two sides of the screen are equally illuminated. In order to facilitate the observation of the screen, it is usually arranged with two mirrors mounted at a slight angle to it, as shown at *M M* in (*c*). *S* is the screen with the grease spot, and the observer looks at the reflection of the two sides of the screen in the mirrors instead of the screen itself. This screen with the mirrors is mounted in a box, which is open at the ends to admit the light from the sources and which is also provided with an opening in the front to enable the observer to see the reflections of the screen.

25. Fig. 13 shows the arrangement of the parts of a simple photometer of the Bunsen type designed by Elmer G. Willyoung for use in connection with lighting stations. *A*, the standard—in this case an incandescent lamp of accurately known candlepower—is at one end, and *B*, the light to be measured, at the other; *D* is the bar on which the carriage containing the screen slides. The part *D* is usually spoken of as the **photometer bar.** *E* is the carriage containing the Bunsen screen. The motor *F* is used to spin the lamp *B* while measurements are being made; the reason for doing this will be explained later. *G* and *H* are two adjustable resistances for keeping the voltage applied to the lamps at the proper value.

26. Fig. 14 shows a Deshler-McAllister photometer—a simple instrument that has been quite largely used by lighting stations for testing the light-giving qualities of the lamps they are using. The principal difference between this

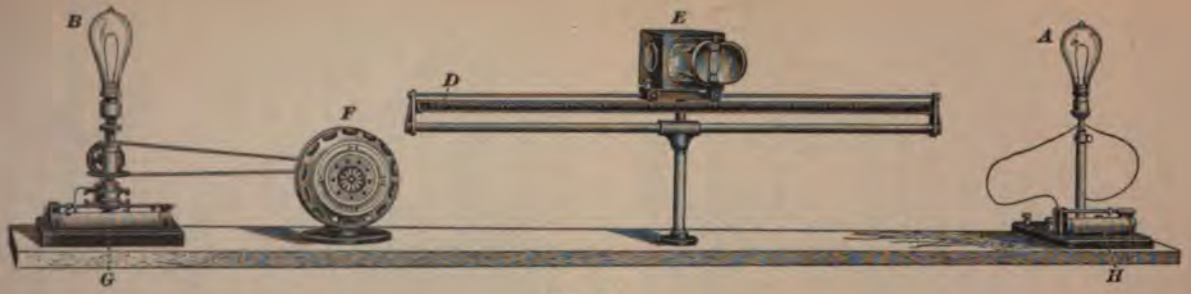


FIG. 13.

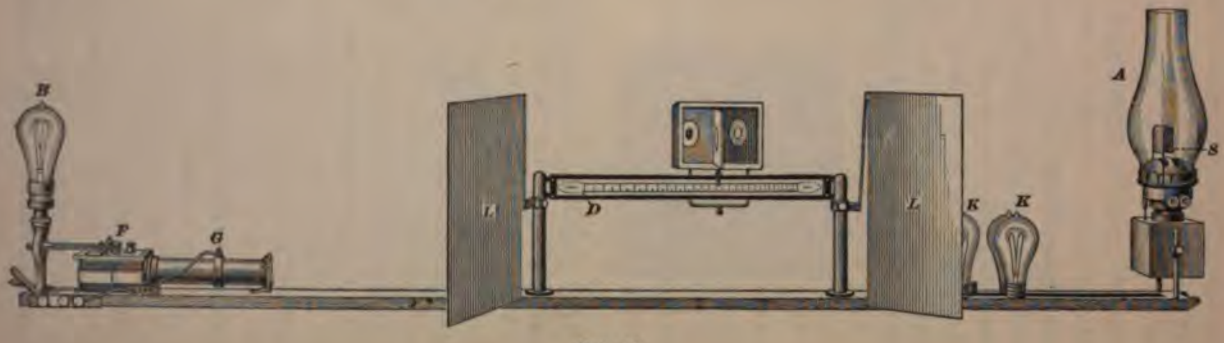


FIG. 14.

instrument and the one previously described is that an oil lamp *A* is used as a working standard instead of an incandescent lamp. The bar is also provided with a scale reading directly in candlepower, though the Willyoung instrument could also be provided with a direct-reading scale if desired. One objection to using an incandescent lamp as a light standard is that its voltage must be constantly watched and kept at the proper amount. It is largely to get around this difficulty that the oil lamp *A* is used. This is an ordinary oil lamp provided with a double wick and an adjustable screen *S*, by means of which the upper and lower ragged edges of the flame are cut off. *K*, *K* are standard incandescent lamps that have been accurately calibrated at the lamp factory and of which the candlepower at the voltage marked on them is known. Each of these standard lamps in succession is placed at *B* and the pointer of the carriage set at the point on the bar corresponding to the candlepower marked on the lamp. The voltage at the lamp is then adjusted by means of the rheostat *G* until it corresponds exactly with that marked. When this has been done, the screen *S* in front of the flame of *A* is adjusted until the grease spot is balanced. The lamp *A* is then of the same candlepower as the standard and may be used for the measurement of other lamps, since after it is once adjusted it is not likely to change, though it should be checked up now and then to make sure that it does not do so. The object in having a number of standard lamps *K* instead of one only is to have a check against any errors that might be caused by changes in the lamps. Screens *L*, *L* are provided to cut off the light from the observer's eyes and a motor *F* is used to rotate the lamp. These station photometers are not expensive, and if properly used, are of great value in detecting poor lamps.

27. After a person has become accustomed to the photometer, good results can be obtained provided the following conditions are fulfilled:

1. The lights, both the standard and the light being measured, should be steady.

[illegible]

photometers just described are arranged so that the lamp may be revolved at the rate of about 180 revolutions per minute, thus giving the average, or mean, horizontal candlepower. The horizontal candlepower does not vary greatly in different directions with lamps as now constructed. This is shown by the irregular curve (Fig. 15). The distance of the points on this curve from the center represents the candlepower in the direction of the radius from that point, and if the candlepower were the same in all directions, this curve would become a circle.

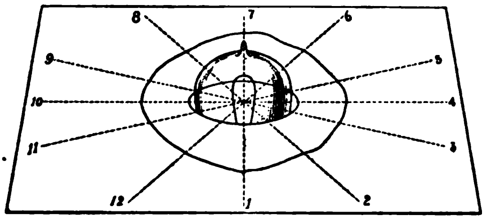


FIG. 15.

29. Vertical Distribution.—Fig. 16 shows the readings for the candlepower obtained in a vertical plane with a filament in the position shown. It will be noticed that, viewed from position *1*, the candlepower is practically zero, because the light is almost completely cut off by the base of the lamp. At points *2* and *4* it is a maximum, because viewed from these points the maximum amount of the filament is seen. At point *3* the candlepower again drops off, because here the filament is seen end on. The curve of horizontal distribution gives an idea as to how the lamp throws light

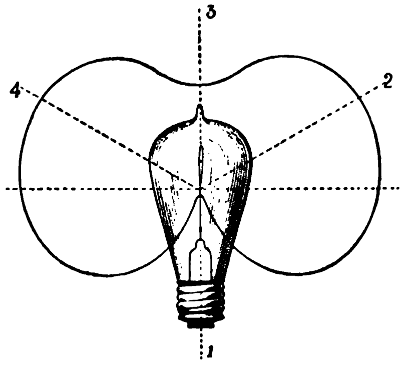


FIG. 16.

in a horizontal plane, and the curve of vertical distribution shows how the lamp behaves as to throwing the light up or down. In speaking of the candlepower of an incandescent lamp, the mean horizontal candlepower is usually meant, and this is most readily obtained by spinning the lamp as described above. In many cases, however, it is customary to measure the candlepower in one direction only, and the error in doing so is not usually very great, because filaments are nearly always twisted and the candlepower does not vary greatly when the lamp is viewed from different directions. In case the lamp is not revolved when measurements are being taken, it should be adjusted with the plane of its filament at such an angle to the photometer bar as will give the mean candlepower. For example, in Fig. 17 suppose that *A B* represents the axis of the bar and that we are looking down on the top of the lamp. The line *C D* will indicate the relative position of the plane of the filament. The angle *a* at which the filament should be inclined will depend on the style of filament used. For plain loop filaments it should be about 60° and for spiral filaments 30°.

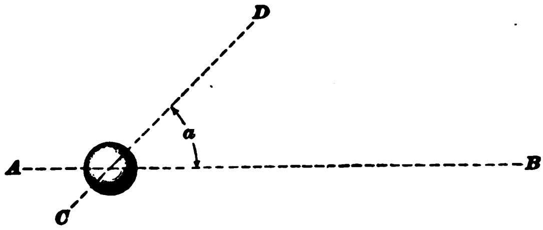


FIG. 17.

30. Mean Spherical Candlepower.—It has just been shown that the intensity of illumination given by a lamp in different horizontal directions varies. Also, its value is different for the various directions taken in any vertical plane passing through the axis of the lamp. If we imagine a lamp hung so that it may be viewed from any direction, it is clear that if we viewed it from any number of different points we would get different values for the candlepower.

If we took a large number of such readings at regular intervals and averaged them up, we would have what is known as the **mean spherical candlepower** of the lamp. In other words, the mean spherical candlepower represents that intensity of illumination to which the irregular illumination of the lamp would be equivalent if it were an average candlepower given out uniformly *in all directions*. In connection with commercial measurements on incandescent lamps, the mean spherical candlepower is not used to any great extent. It is used more in connection with arc lamps. One arc lamp may give a widely different spherical distribution from another, and in comparing such lamps, the mean spherical candlepower forms the fairest basis of comparison.

31. Incandescent lamps are made in a variety of sizes, the most common candlepowers being 4, 8, 10, 16, 20, 32, 50, and 100. The 16-candlepower lamp is the one most generally used. Small lamps of ½, 1, and 2 candlepower are also used for decorative and advertising purposes.

PROPERTIES OF INCANDESCENT LAMPS.

32. Temperature.—The temperature at which the filament of a lamp is worked may be anywhere from 1,250° to 1,350° C. The hotter the filament is worked the greater is its light-giving power per watt consumed. Of course, it is desirable to operate a lamp so that it will give a large amount of light per watt, provided this can be done without injuring the lamp. At a temperature of about 1,350°, an ordinary lamp will give about ⅓ candlepower per watt consumed; a 16-candlepower lamp would at this rate take 48 watts, or 3 watts per candle. At a temperature of 1,300°, the same lamp might give about ¼ candlepower per watt and thus require 64 watts for its operation. Although it is thus advantageous, as far as power consumption goes, to work the lamp at a high temperature, it is found that if the temperature is pushed too high, the life of the lamp is greatly shortened. On the other hand, if the lamp is worked at a very low temperature; it gives a small amount of light compared with the power consumed, and although its life may be long, it is not satisfactory as a light-giving source.

33. Efficiency.—When the efficiency of an incandescent lamp or arc lamp is spoken of, the power consumption per candlepower is meant. For example, if an incandescent lamp required 3.5 watts for each mean horizontal candlepower, its efficiency would be 3.5, or it would be spoken of as a 3.5-watt lamp. This is not a very satisfactory method of expressing efficiency, because, according to this, the larger the power consumption per candlepower, the greater is the efficiency; while in point of fact just the reverse is the case. A much better way to give the efficiency would be to express it as so many candlepower per watt, and in some cases it is expressed this way. Evidently, the greater the number of candlepower per watt consumed, the greater is the efficiency. At present, however, efficiency is nearly always expressed as so many watts per candle. The power consumption per candlepower varies considerably. If the filament is worked at a high temperature, we may get 1 candlepower for every 2.75 watts expended, or even less, but such lamps are apt to have a short life and, in any event, require very steady voltage regulation. In ordinary work, lamps give about .3 candlepower per watt, i. e., they require about 3.33 watts per candlepower. This is a fair value for the power consumption of an ordinary lamp. A lamp may take as low as 3 or 3.1 watts per candlepower when first installed, but its light-giving properties fall off after it has been in operation for a time and the power consumption may run up as high as 3.8 or even 4 watts per candle. From 3.3 to 3.5 watts per candlepower is, therefore, a fair average.

34. Connections for Testing.—When testing lamps, a careful record should be kept of the length of time they have burned, also of the voltage and current. With this data at hand, together, of course, with the readings of candlepower as given by the photometer, the efficiency of the lamp time during the test may be at once determined. Accurate instruments must be used, and their scales should be so divided that the ammeter or mil-ammeter may be read to $\frac{1}{1000}$ ampere and the voltmeter to $\frac{1}{10}$ volt. A variable resistance should also be inserted in series with the lamp so that the voltage across the lamp terminals may be kept nearly constant.

Fig. 18 shows the general scheme of connections. The ammeter *A* is connected in series with the lamp and the voltmeter *V* across its terminals. Readings of *A* are taken with the voltmeter cut out, so that *A* does not measure the current through the voltmeter as well as that through the lamp. A good ammeter and voltmeter are to be preferred to a wattmeter for this kind of work, as the results are more likely to be accurate. Continuous current should, if possible, be used for all testing, as alternating-current instruments are more likely to lead to inaccurate results. Current supplied from a continuous-current dynamo running at constant speed may be used, but it will be found more satisfactory to use current from a storage battery if it can be obtained, as the latter current is perfectly steady. Readings of candle-power, current, and voltage should be taken as nearly simul- v as possible.

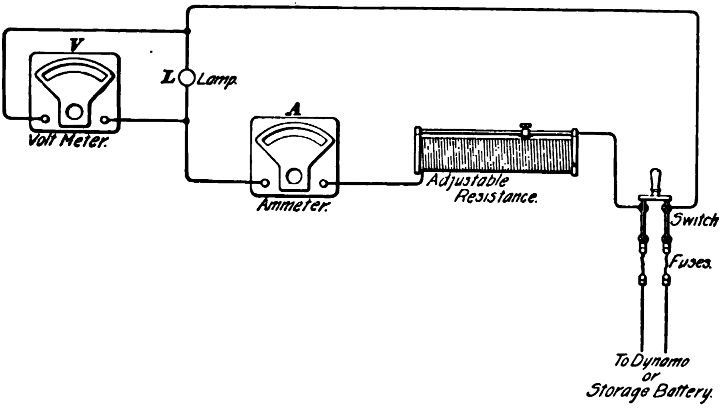


FIG. 18.

35. Lamp Estimates.—With an average power consumption of 3.3 watts per candlepower, a 16-candlepower lamp would require 16 × 3.3 = 52.8 watts. The current that the lamp will require will depend on the voltage at which it is operated. The current in any case can be obtained by the following formula or rule:

$$C = \frac{CP \times W}{V}, \qquad (3.)$$

in which CP = candlepower, W = watts per candlepower, and V the voltage across the lamp terminals.

Rule.—*Multiply the candlepower of the lamp by the watts per candlepower and divide by the voltage at which the lamp is designed to operate.*

EXAMPLE.—A 32-candlepower lamp requires 3.5 watts per candlepower and is designed to operate at a pressure of 110 volts. What will be the current taken by the lamp and what will be the resistance of the lamp when hot?

SOLUTION.—From the above rule, we have

$$\text{Current} = \frac{32 \times 3.5}{110} = 1.02 \text{ amperes, nearly. Ans.}$$

From Ohm's law we have $C = \frac{E}{R}$, or $R = \frac{E}{C}$;

hence,
$$\text{Resistance} = \frac{110}{1.02} = 107.8 \text{ ohms. Ans.}$$

NOTE.—The value of the resistance of an incandescent lamp obtained by dividing the E. M. F. by the current flowing through it gives the hot resistance. The resistance of carbon decreases as the temperature increases. Since the temperature is high in an incandescent lamp, the cold resistance is very much higher than the hot; it may be almost double the hot resistance. In practical work, we are not, as a rule, concerned directly with the cold resistance of the lamps, and when the resistance is spoken of, the hot resistance is meant. A 16-candlepower 110-volt lamp has a hot resistance in the neighborhood of 220 to 250 ohms.

Small incandescent lamps require a larger number of watts per candlepower than large ones. For example, a 4-candlepower lamp requires in the neighborhood of 20 watts; a 6-candlepower, 25 watts; an 8-candlepower, 32 watts; and a 10-candlepower, 37 watts. In general, then, the substitution of a small lamp for a larger one will result in a saving in power, but not in direct proportion. For example, if an 8-candlepower lamp were substituted for a 16-candlepower, the power consumption might be reduced from about 52.8 watts to 32 watts and the candlepower would be cut down one-half.

36. If we allow for loss in the line, it will probably require at least 60 watts at the dynamo terminals for every 16-candlepower lamp operated. Hence, if the output of the dynamo, in kilowatts, is known, the number of 16-candlepower lamps that it is capable of operating may be obtained approximately by the following formula or rule:

$$\text{No. of 16-c. p. lamps} = \frac{K\,W \times 1{,}000}{60}, \qquad \textbf{(4.)}$$

in which $K\,W$ is the capacity of the dynamo in kilowatts.

Rule.—*Multiply the capacity of the dynamo in kilowatts by 1,000 and divide the result by 60. The quotient will give approximately the number of 16-c. p. lamps that the machine is capable of operating.*

EXAMPLE 1.—About how many 16-candlepower lamps should a 12-kilowatt dynamo be capable of operating?

SOLUTION.—

$$\text{Number of lamps} = \frac{12 \times 1{,}000}{60} = 200. \quad \text{Ans.}$$

Sometimes the output of the dynamo is given in volts and amperes instead of in kilowatts. In such cases, the output in *watts* is easily obtained by multiplying the volts by the amperes, and the number of 16-candlepower lamps that the dynamo can operate may then be obtained by dividing by 60 as before.

EXAMPLE 2.—A dynamo is capable of delivering an output of 70 amperes at a pressure of 115 volts. About how many 16-candlepower lamps can it run?

SOLUTION.—The output in watts will be 115 × 70 = 8,050, and since each lamp requires about 60 watts, the capacity of the machine will be $\frac{8050}{60} = 134$. Ans.

NOTE.—When the capacity of a dynamo is given as so many lamps, 16-candlepower lamps are always meant. If 32-candlepower lamps are operated, each 32-candlepower lamp should be counted as the equivalent of 2 of 16-candlepower.

upper curve being for a modern lamp and the lower for an old-style lamp. Both lamps start out with the same candlepower, and the lines show the percentage of the initial candlepower after the lamps have been burning for different intervals of time. There is a steady decline in the voltage of the old lamp from the time it starts burning, and at the end of 500 hours it is only giving 70 per cent. of the light it gave at the start. The candlepower of the other lamp, on the contrary, increases slightly during the first 25 hours, and at the end of 75 hours has gotten back to its original candlepower. It then falls off in candlepower, but at the end of 500 hours is still giving about 77 per cent. of the original amount.

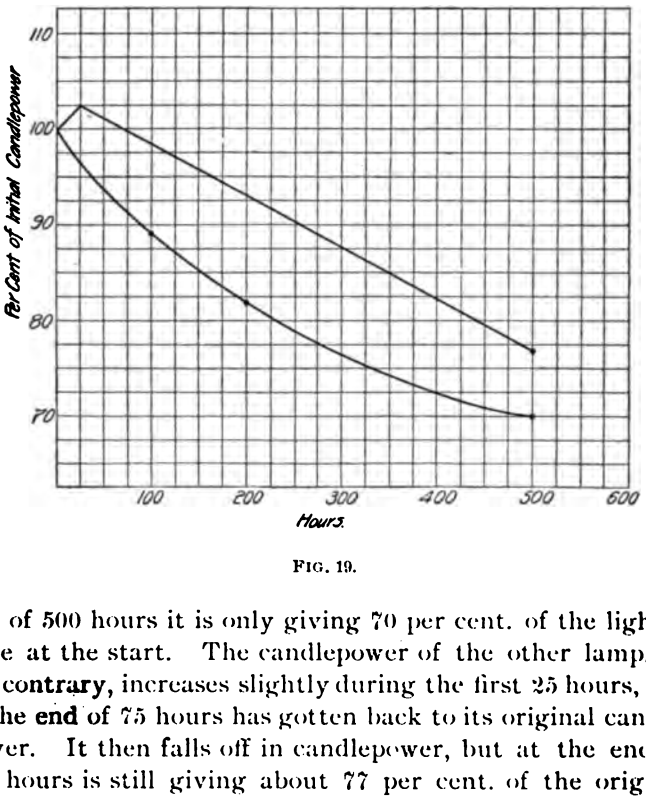


FIG. 19.

41. Voltages.—The voltage of an incandescent lamp is the pressure that must be maintained between its terminals in order that the resulting current shall cause the lamp to give its rated candlepower. By far th incandescent lamps in use are designed for voltages anywhere between the limits of 100 and 115 volts. For example, 100, 104, 110 are common values. When alternating current was first introduced, it admitted the use of low voltages at the lamps, because the current could be transmitted at high pressure and then transformed to low pressure. At that time, it was more difficult to make durable and efficient lamps for 100 or 110 volts than for lower voltages, and a pressure of 50 or 52 volts for the lamps became common. This pressure is not being used on new installations, because there is now no difficulty in making lamps for the higher voltages. A pressure of 80 volts is commonly used for marine work. Of late years, it has become possible to make lamps for 220 to 250 volts, and a number of plants using lamps of this voltage are in successful operation.

In connection with lamp voltages, it may be interesting to note that in the process of manufacture it is impossible to make all the lamps come out at the voltage aimed at. For example, if a lot of 110-volt lamps were to be made up, a great many of them would come out at 108, 109, 111, or thereabouts. It is often a good plan, therefore, for a station to operate at an odd voltage of, say, 107 or 111 rather than at 110, as the chances are that if lamps are ordered for the odd voltages they will be obtained, whereas, if ordered for the even 110 volts, it is probable that 108-volt or 109-volt lamps marked 110 will be supplied, because it would be practically impossible to supply all the lamps of exactly 110 volts without especially selecting them.

42. General Remarks.—Incandescent lamps are made for a wide range of voltage and candlepower. The power consumption per candlepower also varies through wide limits. High-efficiency lamps, in general, will have a short life unless the voltage regulation is very good; hence, high-efficiency lamps should not be used in places where the regulation is poor. In order to determine the current that any lamp will take, its power consumption per candle must be known, and the current may then be calculated as explained in Art. **35.** When making wiring estimates, or, in any case, when the approximate current only is needed, the following values of the current required per lamp may be used:

TABLE I.

Candlepower.	Voltage.	Current. Amperes.
10	110	.36
16	110	.50
32	110	1.00
10	52	.75
16	52	1.00
32	52	2.00

43. Heating.—A 16-candlepower, 64-watt incandescent lamp gives off about 220 British thermal units of heat per hour.

A British thermal unit is equivalent to the amount of heat that is required to raise 1 pound of water from 62° F. to 63° F.

Incandescent lamps give off between 10 and 20 per cent. less heat than gas jets of the same candlepower.

44. Illumination by Incandescent Lamps.—In all methods of wiring, it is necessary to so locate the light that the best illumination may be obtained. In factory lighting, the lights are so placed that they will be as near as possible to the workmen, whether at the machine or vise.

For the interior of stores, general illumination is required. Show windows should be lighted by reflected light only, because exposed light striking the eye will cause the effect of the general arrangement to be lost to the observer. In picture galleries, this same idea should be carried out. House illumination is more for effect than general illumination.

In theater lighting, where the scenic effects depend entirely on a careful adjustment of light intensities, experience is the only guide.

Among other points to be observed in placing lights is the color of the surrounding walls. Dull walls will reflect only about 20 per cent. of the light thrown on them, while a clean, white surface will reflect 80 per cent. The height of the room also reduces the effectiveness of a given light intensity.

One **candle-foot** is considered a good light to read by, which is the illumination given by a standard candle at the distance of 1 foot.

The illuminating value of different lights is as follows:

TABLE II.

Light.	Candle-Feet.
Ordinary moonlight.......	.025
Street lighted by gas......	.030
Stage of theater..........	2.9 to 3.8
Diffused daylight.........	10.0 to 40.0

A clear idea of these various intensities is easily gained by comparison, remembering that *1 candle-foot* furnishes a good light to read by, as stated above.

THE NERNST LAMP.

45. Many attempts have been made to improve the efficiency of incandescent lamps. The efficiency of any light-giving source depends on the temperature of the substance that emits the light. If the temperature is increased, the amount of energy given off in the shape of light becomes greater in proportion to the amount given off as heat, and the efficiency of the lamp as a light-giving source is improved. For example, an incandescent lamp worked above its normal voltage gives more candlepower per watt consumed than if worked at a low voltage; but the high temperature soon burns out the filament. Many attempts have been made to produce filaments that could be operated at a higher temperature than carbon and thus make more efficient lamps. One of these is the **Nernst lamp.** This lamp has not as yet come into extended commercial use, so that we will confine ourselves to a brief description of its principle of action. There are some substances that, while they are good insulators when they are cold, become fairly good conductors when heated to a sufficiently high degree. Glass, for example, when heated to a red heat will conduct electricity. Oxide of magnesium (magnesia), thoria, and a number of other oxides will also conduct electricity when they are heated.

The "glower," or light-giving portion of the Nernst lamp, is a small stick made of oxide of magnesia, thoria, or similar substance. When this stick is heated it conducts current, and this brings the oxide up to a very high temperature, thus making it give light. The temperature attained by the oxide stick is very much higher than that of the incandescent-lamp filament, and the lamp is therefore far more efficient. It is necessary, however, to have a small amount of resistance in series with the glower, in order to make the action of the lamp stable, and this tends to lower the efficiency to some extent. The glower is protected by a small glass globe, but the air is not exhausted. The substance giving the light is already an oxide, so that it cannot be further oxidized by being in contact with the air, and there is no need of placing it in a vacuum. One disadvantage of the lamp is that the glower must be heated before the lamp will start. Various devices for accomplishing this initial heating electrically have been brought out. In the Westinghouse type of Nernst lamp, the glower is heated by being placed directly under a coil of platinum wire wound on a small cylinder of refractory material. When the current is turned on, it heats this coil and thus raises the temperature of the glower until it is able to conduct current. After the glower has started, the heating coil is cut out automatically.

It requires from 15 to 30 seconds for one of these lamps to start. The light given by the Nernst lamp is of a pleasing color, and 1 candlepower can be produced with an expenditure of 1.50 to 2 watts.

METHODS OF CONNECTING LAMPS.

46. Lamps in Parallel.—By far the greater number of incandescent lamps are connected in parallel, as shown in Fig. 20. When lamps are connected in this way, the pressure between the two lines must be kept at a constant value, because if this is not done, the current flowing through the lamps will vary. It must be remembered that the resistance of the lamp cannot change, unless the temperature of the filament changes, because the filament is of fixed dimensions. The current that will flow through any lamp depends on two things, and only two, namely: the pressure between the lines and the resistance of the lamp. The current in each lamp will be equal to the pressure between the mains divided by the resistance of the lamp. So long as the pressure is kept constant, it is easy to see that the turning off or on of any lamp does not affect the others. The current *C* flowing in the mains will increase when lamps are turned on and decrease when they are turned off. As stated above, practically all incandescent lamps are connected in this way, because such an arrangement is extremely simple, and each lamp is independent of the others.

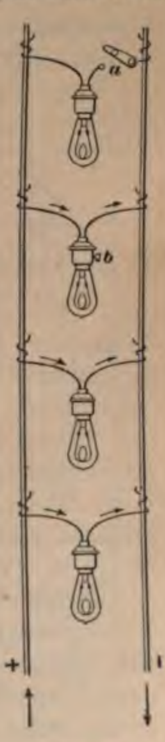


FIG. 20.

47. Lamps in Series.—Lamps are occasionally connected in series, as shown in Fig. 21. This arrangement is used principally for street lighting; it is seldom used for interior work for reasons that will appear later. In this case, the same current flows through all the lamps; hence, their filaments must all be of the same current-carrying capacity. If it is desired to have some lamps of higher candlepower than the others, their filaments must be made longer. The pressure across the terminals of any lamp may be found by multiplying the resistance of the lamp by the current flowing. Also, since the lamps are connected in series, the total pressure required to force the current through the circuit will be the sum of the pressures required for the separate lamps. For example, suppose we had 10 lamps, each requiring a pressure of 20 volts and a current of 3½ amperes; also, 5 lamps each requiring a current of 3½ amperes and a pressure of 40 volts. The total pressure required for the circuit, neglecting the loss in the line, would then be $20 \times 10 + 5 \times 40 = 400$ volts. In this system, the line current is small; hence, it is well adapted for incandescent street lighting, where the area to be covered is large. It should be noted that in a system of this kind the current must be maintained at the value for which the lamps are designed. This means that the pressure between the ends of the line must be raised as more lamps are added to the circuit, because the resistance is increased. Also, the pressure must be lowered when lamps are cut out, otherwise the current would increase and burn out the remaining lamps. In the series system, the current is constant and the pressure varied so as to keep it constant; in the parallel system, the pressure is kept constant and the current varies as the number of lamps in use is increased or decreased. Another point to be noted in connection with the series system is that some means must be provided for maintaining the circuit around the lamps, in case they should burn out;

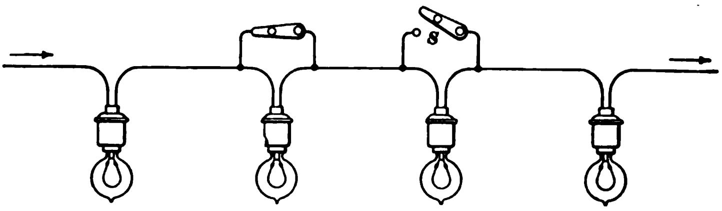


FIG. 21.

otherwise, the breaking of any one lamp would put out all the lights on the circuit. The method by which this is accomplished will be described when this system is taken up in detail. The student will also note that if the number of lamps operated is at all large, the pressure applied to the circuit may be very high. This introduces an element of danger and is the principal reason why series lighting is not used for interior work. Lamps in series may be cut out of circuit by short-circuiting them as indicated by switch *S*, Fig. 21; whereas, in the parallel system they must, of course, be cut out by opening the circuit through the lamp by means of a switch in series with it. This switch may be a separate device, as at *a*, Fig. 20, or it may be in the lamp socket and worked by a key, as at *b*.

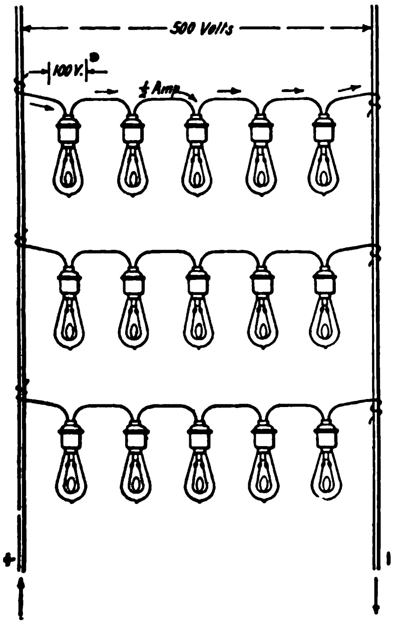


FIG. 22.

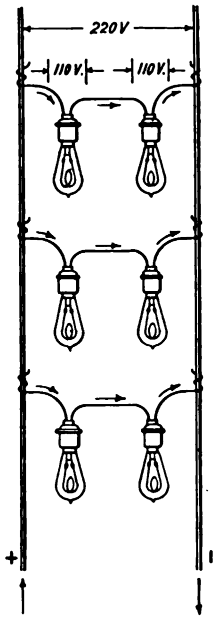


FIG. 23.

48. Lamps in Multiple Series.—This method, sometimes called **parallel series**, is a combination of the two preceding and is used in a number of special cases. Perhaps its widest use is in connection with the lighting of electric street cars; it is also used in mine-lighting work, where lights are operated from the haulage system. This multiple-series scheme of connection is shown in Fig. 22. Suppose, for example, that we have a pair of mains between which a constant pressure of 500 volts is maintained, as on a street railway, and that we wish to operate incandescent lamps on such a circuit. We cannot obtain lamps for 500 volts and a single 100-volt lamp would be burned out instantly if it were connected across the mains. If we wish to use 100-volt lamps, we may connect five of them in series, as shown. With such an arrangement, the current through the series of five lamps would be about ½ ampere and the pressure across each lamp 100 volts. We may connect any number of such series of five lamps across the mains, and if one light goes out, it puts out the other four in the same circuit with it. Also, if any lamp were cut out, by short-circuiting it, the voltage on the other four lamps would become higher than they could stand, because the pressure between the mains is constant, and cutting out the drop through one lamp simply throws that much more pressure on the others. As stated above, this method of connecting lamps is used principally in places where it is desired to operate lamps on power circuits, the voltage of which is usually higher than that of the lamp. Fig. 23 shows a multiple-series arrangement with two lamps in series, a scheme of connection sometimes used for operating lamps on 220-volt power circuit, for example, in mine-haulage plants. By adding the middle, or neutral, wire to Fig. 23, we get the three-wire system, Fig. 24, so extensively used for distribution in large cities.

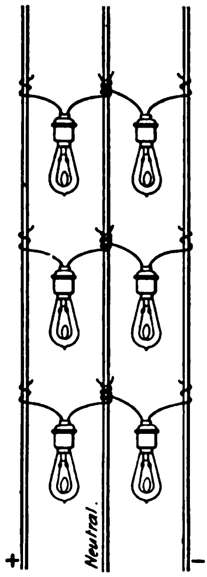


FIG. 24.

The schemes of connection given above cover most of the cases met with in practice. Their use in connection with the different systems of distribution will next be considered.

SYSTEMS OF DISTRIBUTION.

49. It will be necessary to take up at this point the different systems commonly used for supplying the electrical energy to the lamps. The methods of distributing the current to the lamps by means of the wiring in the building will not be considered here, as that part of the subject belongs properly to interior wiring and will be taken up in connection with that subject. The following brief descriptions of the more important distributing systems are intended to point out how the methods already described are applied to electric-lighting work. Current for electric lighting is distributed from the station to the point of utilization in the same manner as for power transmission; in fact, in the majority of cases the electric energy transmitted is used both for lighting and power purposes.

With but few exceptions, the current required for the operation of incandescent lamps is distributed at a constant potential, i. e., the aim is to keep the pressure at the station such that the pressure at the lamps will remain constant no matter what the load may be. If the pressure at the lamps is not maintained uniform within narrow limits, the service will be poor, the life of the lamps short, and the complaints from customers numerous. Where the lamps are run on a constant-potential system, the current transmitted over the lines increases with the load, because every light turned on means just so much more current to be supplied. The consequence is that the drop in the line increases with the load, and in order that the pressure at the lamps shall be maintained constant instead of falling off on account of this drop, the pressure at the dynamo or station must be raised slightly. In any event, no matter what means may be adopted for distributing the current, the aim should be to provide the lamps with a uniform pressure and to see that this pressure is kept uniform, no matter how the number of lamps operated may vary. The distribution should also be designed so as to accomplish the object aimed at with the least possible expense, i. e., the distributing lines should be laid out so as to secure the desired results with the smallest possible amount of copper and loss of energy.

DIRECT-CURRENT CONSTANT-POTENTIAL SYSTEM.

50. Simple Two-Wire System.—This method of distribution is very largely used for small, isolated plants, or any installation where the power is transmitted a short distance only. The lamps are usually operated at 110 volts and the current is supplied by compound-wound dynamos. Fig. 25 shows a single dynamo *G* operating lamps on the simple two-wire system. In this case, two main wires *A*, *A* run from the dynamo, the various switches and measuring instruments being here omitted for the sake of clearness, and the lamps are either connected directly across this pair of mains or are connected across branch mains, as shown at *B*, *B* and *C*, *C*. The lamps are, therefore, simply

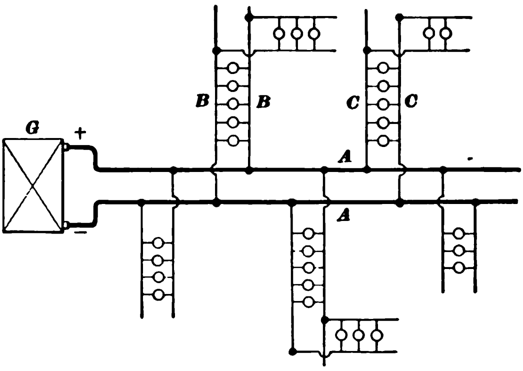


FIG. 25.

connected in parallel, as explained in Art. **46.** This arrangement answers very well for small plants, where only a small number of lamps are operated and where they are not scattered very widely.

51. Feeders and Mains.—If the lamps are scattered over a considerable area, it is best to run out feeders, as shown at *A* and *B*, Fig. 26, to what is known as **centers of distribution,** as at *C* and *D*, and then at these points attach mains *E*, *F* to the feeders. These centers of distribution should be selected so as to lie near the points where the bulk of the light is used. It will be noticed that no lights whatever are attached to the feeders; they simply convey current from the station to the center of distribution, which becomes, as it were, a kind of substation. By this method, a considerable drop can be allowed in the feeders without causing any trouble at the lights. For example, suppose 110-volt lamps were to be operated and a drop of 15 volts was allowable between the dynamo and the last lamp on the line. We may, for example, figure the cross-section of the feeders so that a drop of 13 volts will occur in them. This large drop will allow comparatively

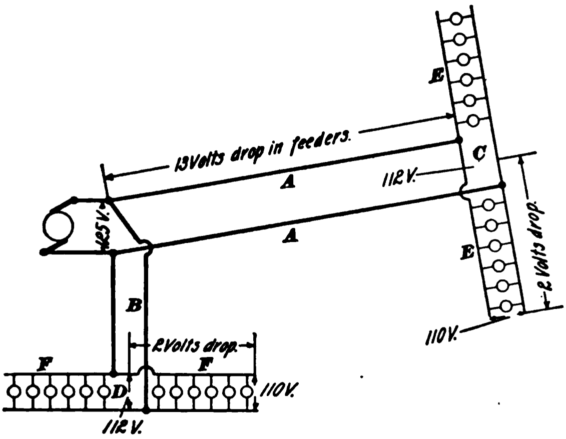


FIG. 26.

small feeders to be used and will not be injurious to the lamps, because the pressure at the point *C* will be maintained at 112 volts, and the variation in pressure along the mains would be but 2 volts, or the balance of the total drop of 15 volts allowed. It is evident that when no current is flowing, there can be no drop in the line, because the drop is the product of the current and the line resistance. As the current increases, the drop increases, so that in the above case the dynamos would have to be adjusted to give a pressure of 110 volts at no load and 125 volts at full load; in other words, the dynamo would be overcompounded so as to give a rise in voltage of 15 volts.

52. The arrangement just described is known as the **feeder-and-main system,** and the advantages of such a system may be summed up briefly as follows:

1. It allows the use of a large drop in the feeders carrying the current to the point where it is distributed, thus permitting the use of comparatively small conductors and thereby cutting down the expense.

2. It allows this large drop without introducing large variations in the voltage obtained at the lamps.

3. It allows the district lighted to be divided into sections, each supplied by its own feeder, and thus admits of each section being controlled independently from the station.

53. Three-Wire System.—The simple two-wire system, even if operated on the feeder-and-main plan, requires altogether too much copper to admit of very extended use. For moderate distances, the three-wire system is used. Fig. 27 shows this system using feeders and mains as applied to lighting work. A large amount of lighting is carried out on this plan in New York, Philadelphia, and other large cities. It is not confined to direct current alone, but is also largely used in connection with alternating current. We have here the two dynamos *A* and *B* connected in series and supplying current through the feeders *1*, *2*, *3*, etc. to the different centers of distribution where the mains *a*, *b*, *c* are attached. The use of this arrangement effects a considerable saving in copper over the two-wire system; the pressure commonly used is 110 volts on each side of the circuit, or

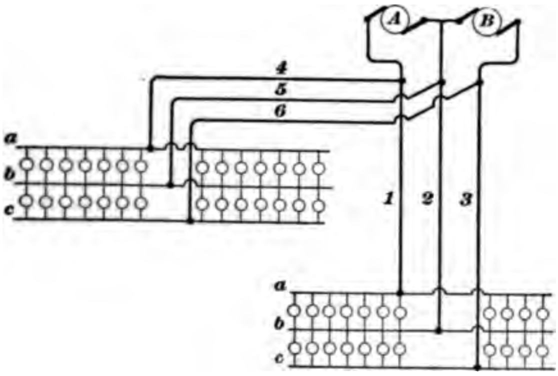


FIG. 27.

220 volts between the outside wires. In some recent plants, 220-volt lamps are used, thus giving 440 volts between the outside wires.

54. Special Three-Wire Systems.—The ordinary three-wire system has the disadvantage of requiring two dynamos. If the load were absolutely balanced, one 220-volt dynamo would alone be sufficient, but in most cases an accurate balance cannot be obtained. A number of different systems have been devised whereby a large 220-volt dynamo can be operated on the two outside wires and the unequal distribution of the load taken up by a balancing arrangement of small capacity compared with that of the dynamo.

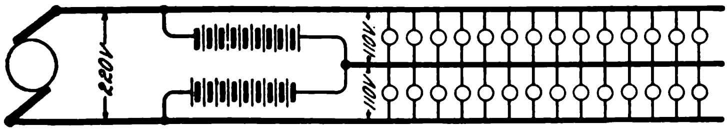


FIG. 28.

55. Fig. 28 shows one of these systems where the unbalancing in the load is taken care of by means of the storage battery connected as shown. The middle point of this battery is connected to the line. The 220-volt dynamo is connected to the outside wires, and if a larger current is needed on one side of the battery than on the other, the extra current is supplied from the battery. It is not, however, generally advisable to use a battery in this way for maintaining the balance continuously as the cells become unevenly discharged. When batteries are used on three-wire systems, they are usually connected across the outside lines and a switch provided to connect their middle point with the neutral, so that they can be used for balancing in case of necessity.

56. Fig. 29 shows a three-wire system fed by a 220-volt dynamo *A* in conjunction with a motor-dynamo *a a'*. This motor-dynamo is sometimes called a **balancing set** or **balancer.** The armatures *a*, *a'* are mounted on the same shaft and connected in series, the mid-point *n* being connected to the neutral wire. The fields of these two machines are connected across the mains, as shown at *f f'*. When one side of the system is more heavily loaded than the other, the machine on the heavily loaded side runs as a dynamo and helps to supply current to that side, while the machine on the lightly loaded side absorbs power and runs as a motor, thus equalizing the load. Take, for example, the special case shown in Fig. 29, where we have 12 lamps on one side and 6 on the other. We will have 18 lamps to be supplied with power from the 220-volt machine *A*. Allowing 55 watts per lamp, this gives 55 × 18 watts and, hence, $\frac{55 \times 18}{220} = 4\frac{1}{2}$ amperes. The current flowing out on *F* and back

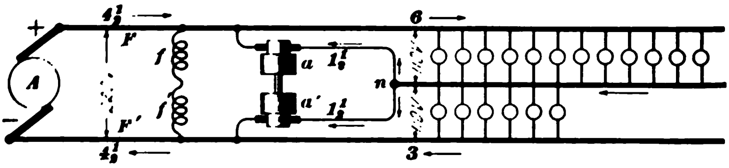


FIG. 29.

on *F* must, therefore, be 4½ amperes. The upper side of the three-wire system requires 6 amperes and the lower side 3, because we have 12 lamps in parallel in the one case and 6 in the other. We have, then, 3 amperes coming back through the neutral, of which 1½ flows through *a'*, running it as a motor and generating 1½ amperes in *a*. This 1½ amperes is added to the 4½ in line *F*, thus making the 6 required for the upper side. By following the current as indicated by the arrows, the student will understand how the balance is maintained. If the lower side should become more heavily loaded than the upper, the current in the neutral wire would be in the opposite direction and the action of *a* and *a'* would be reversed; that is, *a* would act as the motor and *a'* as the dynamo. This motor-dynamo or balancer does not have to be placed in the station; it may be placed at a point near the center of distribution, thus requiring only the two feeders *F* and *F'* to be run back to the station, and thus avoiding the necessity of running the neutral wire all the way back, and thereby effecting a saving in copper. In the above illustration we have neglected the losses in the balancing set. As a matter of fact, machine *A* would furnish more than 4½ amperes in order to make up for the losses in *a a'* and supply the lamps as well.

57. In most large stations operating on the three-wire system, the amount of unbalancing is usually small compared with the total load carried, so that the capacity of the balancing arrangement is, as a rule, small compared with that of the main dynamo. By far the greater part of the distribution on the three-wire system is, however, carried out by the ordinary two-dynamo arrangement shown in Fig. 27.

58. Voltage Regulation.—In stations where a large number of lamps are operated, it is usually necessary to have several distinct feeders running to the different districts to be lighted or supplied with power. Some of these feeders may be long, others quite short. In order, therefore, to keep the cross-section of the long feeders within a reasonable size, a larger drop must be allowed in them than in the short feeders. It is necessary, then, to have some means of supplying the long-distance feeders with a higher pressure than those supplying the nearby districts. Of course, the voltage on the short feeders might be cut down by inserting resistance in series with them, and this, in fact, has been done in some cases. Such a method is, however, wasteful of power and is not to be recommended.

59. A common method is to use separate dynamos for supplying the long-distance feeders, and simply run these dynamos at a higher voltage than those supplying the short feeders. This is an excellent method where the separate dynamos are available, but frequently this is not the case. When only one dynamo or set of dynamos is at hand for operating the whole system, the best plan is to run the machines at the lower pressure suitable for the short feeders, and use a "**booster**" to raise the voltage on the other

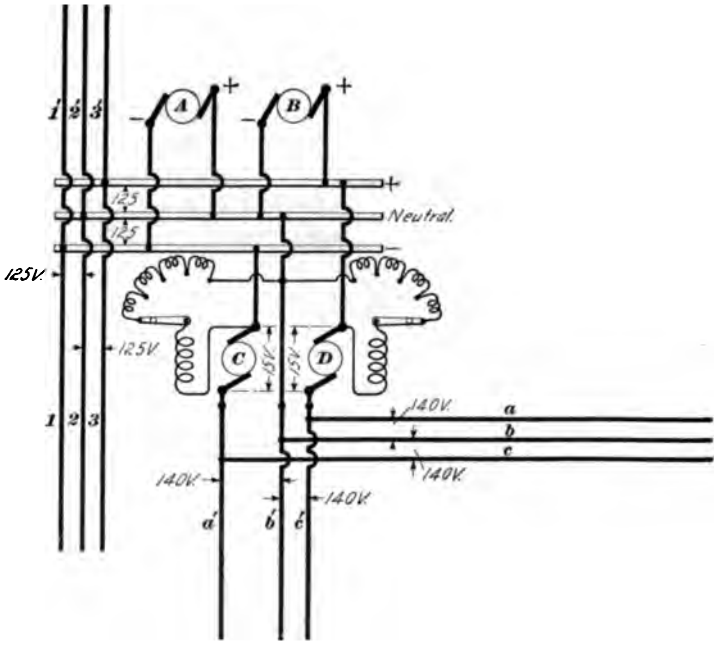


FIG. 30.

feeders. Fig. 30 will indicate what is meant by this arrangement. The plan shown is for the three-wire system, though the same scheme may be used on a two-wire system and is, in fact, largely used on such systems in connection with electric railways. In Fig. 30, *A* and *B* are two dynamos operating on the three-wire system and supplying current directly to the short feeders *1*, *2*, *3*, *1'*, *2'*, *3'*. Feeders *a*, *b*, *c* and *a'*, *b'*, *c'* run to outlying points and, therefore, must be supplied with a higher pressure than the other feeders. We will suppose, for example, that each dynamo generates 125 volts and that the long-distance feeders require 140 volts between the outside and neutral wire; 15 volts must, therefore, be added to each dynamo voltage. This is accomplished by the "boosters" *C* and *D* connected as shown. The boosters are small dynamos that are driven either by a steam engine or, more frequently, by an electric motor. The fields of these machines are separately excited from the mains and the armatures are connected in series with each of the outside wires, as shown. The armatures of the boosters must be capable of carrying all the current used on the long-distance feeders and be able to generate a pressure equal to that by which the voltage is to be raised. For example, in this case the booster armatures would generate the extra 15 volts required and thus give 140 volts on the feeders *a*, *b*, *c* and *a'*, *b'*, *c'*. By varying the field rheostat of the boosters, the voltage on the feeders may be adjusted. Boosters are about the same as other dynamos in general appearance, except that they usually have very large commutators and brushes compared with other dynamos of equal capacity, because they have to carry a large current through their armature. If the connections of the booster armatures were reversed, it is evident that they would lower the voltage instead of raising it.

60. Five-Wire and Seven-Wire Systems.—The three-wire system has been still further extended so as to make use of higher potentials by employing four dynamos in series and three neutral wires This allows the use of

440 to 500 volts between the outside wires and permits a still larger area to be covered than by the three-wire system. Seven-wire systems using six dynamos in series have also been used, and the five-wire system especially has been successfully applied on the Continent of Europe. Five-wire and seven-wire systems have been very little used in America, the practice being to use alternating-current methods of distribution if pressures higher than those given by the 110–220-volt or 220–440-volt three-wire systems are required. The use of three-wire systems with 220-volt lamps and 440 volts across the outside wires is gradually extending, because the higher pressure allows larger areas to be supplied and effects a saving in copper over the 110–220-volt system.

DIRECT-CURRENT, CONSTANT-CURRENT SYSTEM.

61. This system is very seldom used for incandescent-lighting work. It was in use to some extent in the early days of electric lighting, when a few incandescent lights were operated in series with direct-current arc lamps. In such systems, the current used was a direct one, furnished usually by a machine of the T. H., or Brush, type, and this current was maintained at a constant value by the variation in E. M. F. brought about by the automatic regulator. There were many objections to operating incandescent lamps in this way; each lamp had to be provided with a cut-out of some kind to prevent the circuit being broken in case a lamp burned out; such circuits also required a high pressure for their operation, and this rendered the use of incandescent lamps so operated dangerous for interior illumination.

ALTERNATING-CURRENT, CONSTANT-POTENTIAL SYSTEM.

62. Alternating current at constant potential is very extensively used for incandescent lighting, because this method allows lights to be operated over large areas with a comparatively small loss and a small expenditure for copper. The distribution may be carried out either by means of the single-phase, two-phase, or three-phase system. If the current were intended for operating lights only, the single-phase scheme would be used, as it is simpler than either the two-phase or three-phase arrangements. Most modern lighting plants, however, are equipped so that they can operate motors as well as lights, and, hence, it is now customary to install multiphase systems rather than single-phase.

63. Single-Phase System.—When alternating current first came into use for electric lighting, a simple alternator was used to supply current at a constant pressure. This current was transmitted over the line, and at the various points where it was utilized, transformers were installed to step down the voltage to an amount suitable for the lamps. Each customer usually had his own transformer. If the system was small, only a single pair of lines or feeders was run from the station; in case the area lighted was large, a number of feeders supplying different sections were used, as previously described for the direct-current system. The pressures first used were 1,000 volts on the primary mains and 50 or 52 volts on the secondary. As the construction of alternators, transformers, and lamps was brought to a higher stage of perfection, the pressures were increased to 2,000 volts primary and 100 to 110 volts secondary. The frequency used in the early plants was usually from 125 to 133 cycles per second; in later plants, 60 cycles has become common practice.

64. The great advantage of this system over the direct current lies, of course, in the use of the high pressure for transmitting the current. The introduction of alternating current rendered possible the lighting of many places that could not afford the expense of installation that would be necessary if direct current were used. It also rendered available water-powers located at some distance from the center to be lighted.

65. It was formerly customary, in connection with systems of this kind, to install small transformers for each customer, as shown at *A*, *B*, *C*, Fig. 31, and if a large amount of current were required at any point, a number of transformers were connected in parallel, as shown at *K*. This was necessary because transformers were not then made in large sizes. On account of the objections, as before stated, to running a number of small transformers in parallel, it has become the practice to make use of a system of secondary mains supplying a number of customers and to feed these secondary mains from a few large transformers, as shown in Fig. 32. In this case, we have the primary mains *A*, *B* running from the station and feeding the large transformers *T*, *T*, as shown. The distributing secondary mains are usually arranged on the three-wire system, as indicated at *C*, thus allowing a considerable area to be supplied from one pair of transformers. The current may, however, be distributed by secondary two-wire mains

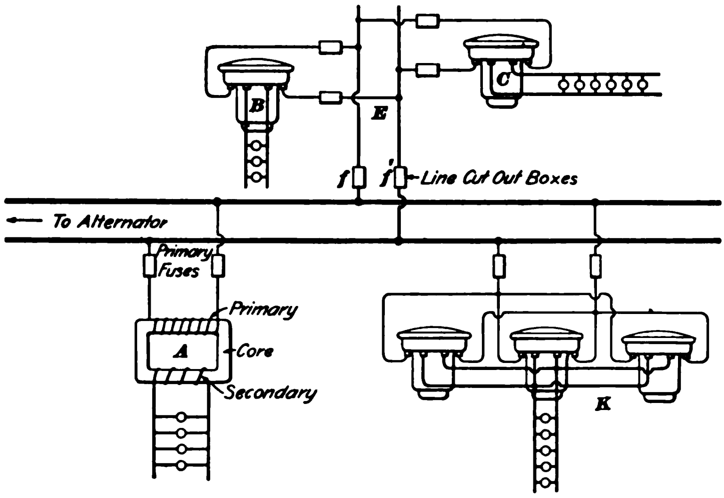


FIG. 31.

if the lights are close at hand. Scattered customers must, of course, be supplied by individual transformers, as in Fig. 31.

The small transformers are usually mounted on the pole outside the building to be lighted. Large transformers are mounted indoors or in substations. The use of secondary mains greatly reduces the number of transformers to be kept in repair and otherwise looked after; it also effects a considerable saving in power, owing to the higher efficiency of the large transformers. Where branch lines, as shown at *E*, Fig. 31, are taken off the main feeders, main-line cut-out boxes *f*, *f'* should be installed as indicated. The secondary-main arrangement can generally be used to advantage for furnishing light to the business part of a town, while in the residence part it is frequently necessary to use individual transformers on account of the customers being scattered. The above remarks in reference to secondary mains apply also to lighting systems using two-phase or three-phase distribution.

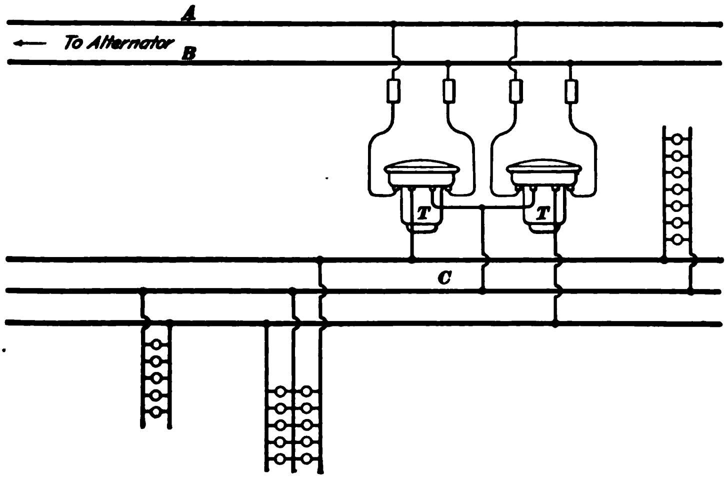


FIG. 32.

66. Two-Phase System.—This system of distribution for incandescent-lighting work has come largely into use, not because it is any better than the single-phase system, so far as the lighting is concerned, if, in fact, it is as good, but because it enables both lights and motors to be operated from the same dynamo. The general scheme of distribution is the same as that just described for the single-phase system. In a two-phase system of this kind, an effort should always be made to have the load balanced on the two phases, otherwise an uneven distribution of voltage is apt to result. Motors may be operated from the same lines as the lamps, but it is better practice to have separate feeders to supply the motors.

67. Three-Phase System.—This system was introduced for the same reason as the two-phase system, i. e., to permit the operation of motors. The ordinary three-phase system requires only three wires. In a few cases, however, where the load is liable to be unbalanced, a common return wire is used The transformers may be connected according to any of the methods already described. Where three wires are run from the secondaries, the voltage between any pair of wires is the same, so that the lamps will burn with the same brilliancy across the outside wires as across either of the others; in this respect, therefore, it is different from an ordinary Edison three-wire system. Also, the voltage between any pair of the primary wires is the same, whereas in the three-wire, two-phase system, the pressure between the two outside wires is about 1.414 times as great as the pressure between the middle and either outside wire.

68. Mixed Systems.—Before leaving the subject of constant-potential alternating-current systems, it will be well to consider the combined use of alternating and direct current as applied to the distribution of light and power. In many large cities, extensive installations on the Edison three-wire system have been made in the past for the operation of both lights and direct-current motors. These were supplied from stations located as close as possible to the centers to be supplied. As the area to be supplied spread, and as alternating current became more extensively used for power-transmission work, these companies adopted the plan of supplying the existing systems with power from substations fed from one central station, or perhaps from a distant water-power plant.

In order to supply direct current to the distributing system, rotary converters may be used, or, as is done in some cases, alternating-current motors may be used to run direct-current dynamos. Fig. 33 shows the scheme referred to. Alternating current is transmitted from the central station at *A*, usually by means of the three-phase system, to the substations *B* or *C*, where it is stepped down by means of transformers *T*, *T*, *T*. The current may then be sent through rotary converters *R* and fed into a three-wire system, as shown, or it may be fed to an alternating-current motor *M* that is coupled to direct-current machines *O*, *O*. Very often arc lights are also supplied from these substations by coupling the alternating-current motor to arc-light dynamos, and in other cases the rotary converters may be used to feed a street-railway system.

A large amount of lighting is carried out, especially in cities, by using the plan just described. Fig. 34 shows a motor-generator set used for transforming from three-phase alternating to three-wire direct current. The three-phase synchronous motor *A* receives current from transformers after it has been stepped down from the high-tension line that transmits it from the central station. The motor drives the two direct-current dynamos *B* and *C*, which are connected in series and supply current to the three-wire system.

For electric-lighting work, it has been found that the use of a synchronous motor driving direct-current generators gives better results than rotary converters, because the former arrangement maintains a steadier voltage on the direct-current side, a feature of great importance in connection with incandescent lighting. If the voltage supplied

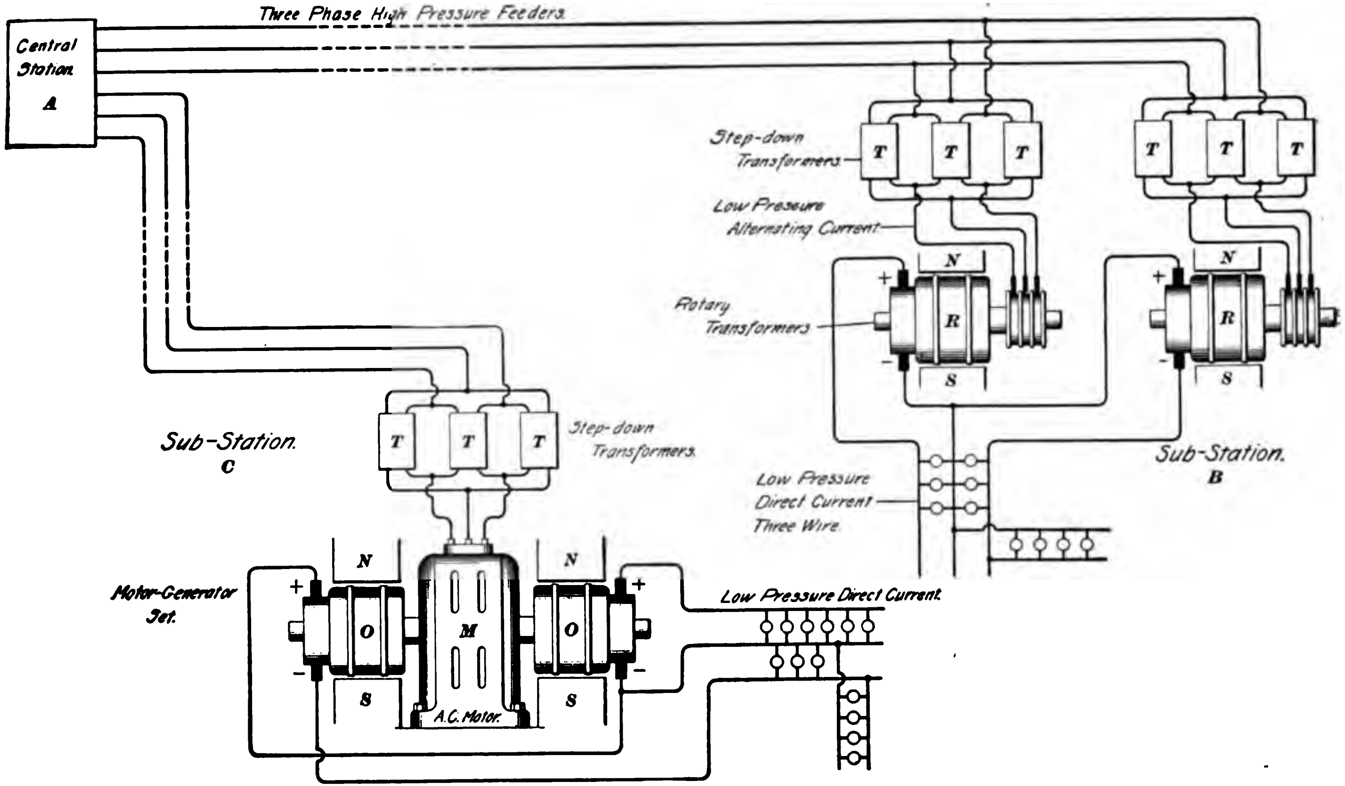

Three Phase High Pressure Feeders
Central Station A
Step-down Transformers
T
Low Pressure Alternating Current
N
R
S
Rotary Transformers
Sub-Station. B
Low Pressure Direct Current Three Wire.
Sub-Station. C
Step-down Transformers.
Motor-Generator Set.
O
M
A.C. Motor.
Low Pressure Direct Current

FIG. 38.

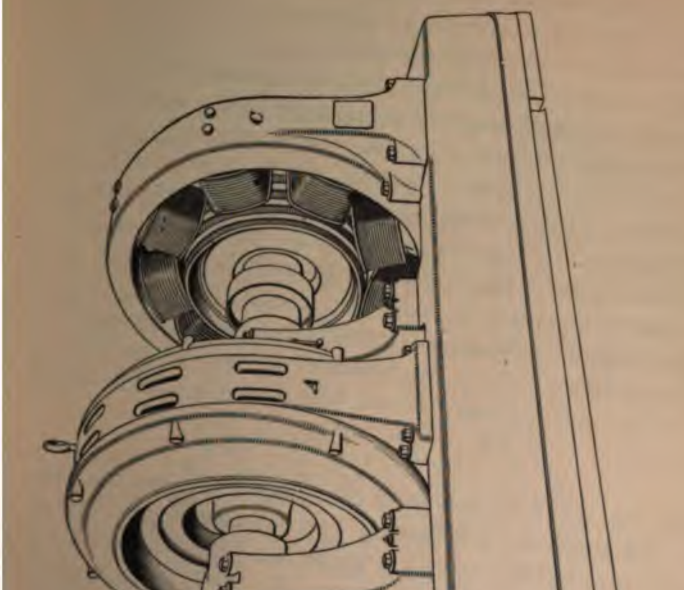


FIG. 54.

to the alternating-current side of a rotary varies, the direct-current voltage will also vary because there is a fixed ratio of transformation between the two voltages. Consequently, all the bad effects of drop in the alternating-current transmission line are felt on the direct-current side, and therefore cause fluctuations in the lamps. If, however, synchronous motors are used to drive separate direct-current machines, the speed of the motor will be constant so long as the speed of the distant dynamo is constant, no matter what may be the fluctuations in the voltage delivered, because the motor is bound to run in synchronism. Since the voltage of the direct-coupled dynamos is constant so long as the speed and field excitation remain the same, it is easy to see that the use of the motor-generator set will give the better voltage regulation.

69. It will be seen from the preceding that the use of constant-potential alternating current of the two-phase or three-phase variety allows a great flexibility in the kind of apparatus operated from one station. If it is necessary to have direct current for any purpose, the transformation is easily effected. In general, where rotary transformers or alternating-current motors are used, it is desirable to have a low frequency, say, about 25 or 40. On the other hand, the frequency should not be below 40 cycles per second if the current is to be used for lighting. A high frequency calls for less expensive transformers, and between all these requirements, which are more or less conflicting, a frequency of 60 has been very generally adopted for systems where the current is used both for light and power. Where power alone is supplied or where the current is used for operating rotary transformers, the frequency may be as low as 25, as in the case of the Niagara transmission plant.

70. Use of Frequency Changers.—In the last article, mention was made of the fact that where rotary converters are extensively used it is customary to use a low-frequency current at 25 or 40 cycles. It sometimes happens that in connection with such installations a comparatively small amount of alternating current at a higher frequency is required, as the frequency of 25 cycles would be too low to operate arc or incandescent lamps in a satisfactory manner. High-frequency current may be obtained from low-frequency by using a low-frequency motor to drive a high-frequency dynamo or by using a **frequency changer.**

Fig. 35 shows a frequency changer of a type used in connection with lighting work. It consists of a synchronous motor *A* direct connected to an induction motor *B* of special design. Motor *A* is driven by current supplied from the armature of *B*. The current to be changed is led into the stationary field winding of *B*, and the high-frequency current is taken from the armature of *B* by means of the collecting rings *C*. The armature of an induction motor always revolves at a slightly lower speed than the magnetism set up by the field windings, the difference in speed between the armature and the field being known as the **slip.** If the armature were held from turning, the frequency of the currents set up in its windings would be the same as the frequency of the current in the field; in other words, the machine would then be acting like an ordinary transformer. As the motor is allowed to run up

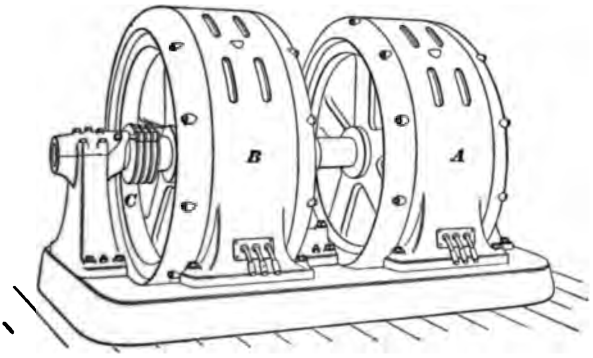


FIG. 35.

to speed, the frequency of the armature currents becomes slower and slower until the motor runs at a speed only slightly lower than that of the field, and the frequency of the armature currents drops down to from 2 to 5 per cent. of that of the field current, depending on the amount of slip. Now suppose that instead of letting the armature run in the direction it ordinarily would, we drive it in the opposite direction. The effect on the frequency of the currents in the armature is then just the opposite, i. e., the frequency, which is the same as that in the field at standstill, increases as the armature is revolved in the opposite direction by means of motor *A*. If it were run up to its regular speed in the opposite direction, the frequency would be just doubled. If it were driven at half the normal speed in the opposite direction, the frequency would be made one and one-half times as great. For example, if a frequency of 40 were to be raised to 60, the armature would be driven in the opposite direction at half its ordinary speed. Frequency changers of this kind are used, among other places, in connection with the Brooklyn lighting system, and also at Buffalo, where the 25-cycle current from the Niagara plant is changed to 62 cycles for use in connection with lighting work.

ALTERNATING-CURRENT, CONSTANT-CURRENT SYSTEM.

71. This method of distribution is used for operating incandescent street lights in series and has been used quite extensively for that purpose. It allows street lighting to be carried out in connection with a regular constant-potential lighting plant, and such plants are thereby enabled to undertake street lighting with very little expense for station apparatus. Of course, street incandescent lamps could be operated directly from transformers and, in fact, they often are run in this way. As a rule, however, they would be scattered too much to be operated economically in parallel, and hence the series system was developed for this work.

When a number of lamps are connected in series in a circuit, the current in that circuit must be kept at the same value, no matter how many lamps are in operation. The term constant current, as applied to this system, implies, therefore, that the current is maintained at a constant value and not that the current is a direct or continuous one. As mentioned above, such circuits are run from constant-potential alternators, a regulator being used in each circuit to keep the current at a constant value. The series-incandescent system of street lighting is especially useful for small plants, where it would not pay to install separate arc-light dynamos. The system is also used in larger places on streets that are very heavily shaded or in alleys or other places where an arc light is hardly necessary.

72. Fig. 36 shows a series of incandescent lamps *l*, *l* connected across an ordinary constant-potential circuit fed by the alternator *A*. Suppose, for example, that the pressure generated by the dynamo is 1,000 volts; then if each lamp required, say, 20 volts, 50 lamps would have to be run in

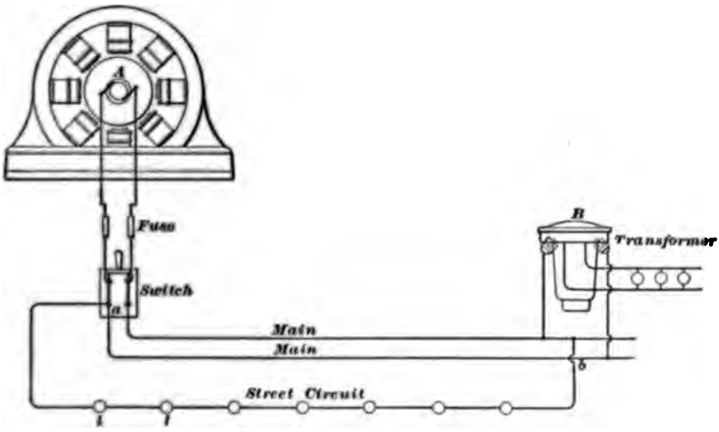


FIG. 36.

series in order to take up the full voltage of the dynamo. Lamps for use on circuits of this kind are often made for a current of 3½ amperes and a pressure of 20 volts. Such lamps have short, thick filaments, and are generally of the shape shown in Fig. 4. Unfortunately, lamps with short, thick filaments are not nearly as efficient as the ordinary 50-volt or 110-volt lamp with a long, thin filament. For this reason, some of the more recent systems of series-incandescent lighting employ circuits using 50-volt or 100-volt lamps, and use a correspondingly smaller number on each circuit. This is the case with the Westinghouse series system to be described later. So long as none of the lamps burn out, the current in the circuit will remain constant, because the line pressure and the resistance of the lamp circuit are constant. Each lamp must be provided with some means for maintaining the continuity of the circuit in case a lamp breaks down, otherwise all the lamps on the circuit would be extinguished. One of the most common devices for preventing an interruption of the circuit is the **film cut-out,** the principle of which will be understood by referring to Fig. 37. This shows the under side of a lamp base; the flat spring *a* is attached to one terminal and is separated from the other terminal by the film of paper *b*. Ordinarily the pressure between the lamp terminals is equal to the drop through the lamp and is quite small. If, however, the lamp should burn out, the current in the circuit ceases flowing for an instant, thus causing the pressure between the lamp terminals to at once rise to the full pressure of the dynamo, because the current becomes zero and the drop in the line and lamps also becomes zero. This pressure is more than the film can stand, and it is at once punctured, thus allowing *a* to touch the other terminal and maintain the circuit. The film cut-out simply maintains the continuity of the circuit without inserting a resistance of any kind to take the place of the lamp, and the current would, therefore, increase if some means were not adopted for regulating it at the station. There are several

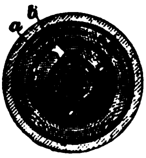


FIG. 37.

arrangements designed for this purpose. Two of the most common are the **lamp-board regulator** and the so-called **C. R. regulator.**

73. The Lamp-Board Regulator.—The principle of this regulator will be understood by referring to Fig. 38. The current is kept at its proper value simply by cutting in a lamp at the station whenever one on the circuit burns out. This board, on which are mounted a number of lamps *l*, *l*, *l*, is placed in the station, and the extra lamps connected in series with the line through a switch *s* and an ammeter *a*. The ammeter indicates when the current is at its proper amount, and if a lamp on the line goes out, the reading at once increases. By moving the handle of the switch *s*, any number of lamps desired may be cut in and the current maintained at its proper value until the lineman is able to go around and replace the broken lamps. The figure is only intended to show the general principle of the lamp board; the actual arrangement of the parts varies in different cases.

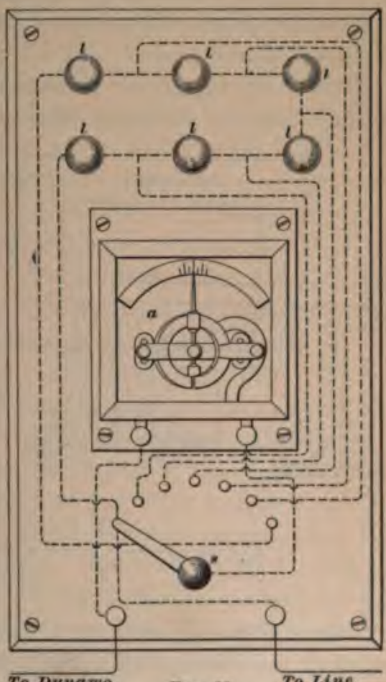


FIG. 38.

74. The C. R. Regulator.—This regulator was brought out by the General Electric Company to replace the old lamp-board method of regulation. In many cases it is desirable to have some kind of regulator that will not only compensate for any lamps that may burn out, but that will also allow a wide variation in the voltage applied to the circuit. For example, we might wish to run a circuit having 40 20-volt lamps from a 1,000-volt alternator. The series of lamps would only require 40 × 20 = 800 volts, and if the lamp board were used, 10 lamps would have to be inserted in the station to take up the extra 200 volts, neglecting the drop in the line. This would be an expensive and wasteful method.

The C. R. regulator is simply a special kind of transformer that is so made that its secondary voltage may be added to or subtracted from that of the dynamo. The operation of this regulator will be understood by referring to Fig. 39. Two coils *A B* and *C D* are wound on a laminated iron core. The coil *C D* is divided into a number of sections, and connections are brought out to the contact blocks *a*; *h* and *g* are two contact strips in the form of circular arcs, *h* being connected to one end of the lamp circuit and *g* to one end of the coil *B*, which is also connected to one of the primary lines. The other end of the primary coil is connected to the circuit and to the other primary wire, as shown at *A*. An ammeter is also included in the circuit to show when the current is at its proper value. The contact pieces *c*, *f* make contact between the circular arcs and the coil terminal pieces *a*, and are so arranged that when a wheel is turned they move towards each other or away from each other, as the case may be. They are also arranged so that they may move past each other.

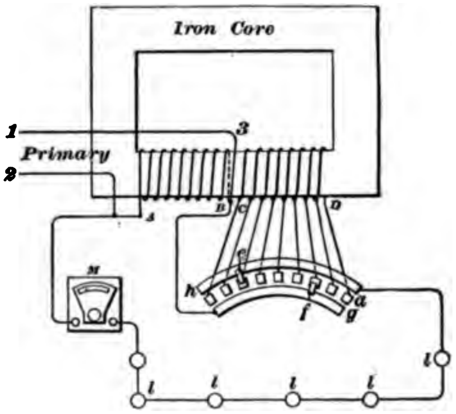


Fig. 39.

Suppose that both e and f rest on the same block in the center of the dial; then, the current flows from the line through the path $1-3-B-g-f-e-h-l-l-l-M-2$, and the pressure applied to the lamp circuit is the same as that supplied by the alternator. A current will also flow through $A B$, because this coil is connected directly across the line, just like the primary coil of a transformer. This current will set up an alternating magnetism around the iron core and an electromotive force in the coil $C D$. If now we connect any of the turns of $C D$ in series with the lamp circuit, the pressure applied to the lamps will be greater or less than the dynamo pressure, depending on whether the E. M. F. induced in the part of $C D$ cut in is opposed to or aids the E. M. F. of the dynamo. Suppose the regulating wheel to be moved so that the contact pieces are in the position shown; the current will flow through that part of the coil $C D$ included between the contacts e, f, and we will suppose that the connections are such that the E. M. F. of this portion of the coil is added to the line. If the handle is turned the other way, so that the sliding pieces e and f move past each other and thus exchange places, it is readily seen that the effect is to make the current pass through the portion of the coil between e and f in the opposite direction to what it did before; hence, with the contacts in this latter position, the line E. M. F. will be diminished by the E. M. F. induced in the portion of the coil cut in. It follows, then, that with this arrangement, the E. M. F. applied to the line may be raised or lowered by the E. M. F. supplied to the coil $C D$. For example, in a regulator designed for a circuit of 1,100 volts, the adjustable coil is wound for 230 volts and is divided into 23 sections of 10 volts each. The voltage on the line can, therefore, be varied from $1,100 - 230$ to $1,100 + 230$, i. e., from 870 to 1,330 volts. This allows quite a wide variation in the number of lamps that can be operated on a circuit and gives at the same time a ready means of adjusting the current in case a few lamps happen to burn out.

Fig. 40 shows the general appearance of one of these regulators. The regulating dial is seen in the center and is so arranged that when the wheel is turned, one arm moves in one direction and the other arm in the opposite direction. The switch at the top of the board serves to disconnect the regulator from the circuit and dynamo.

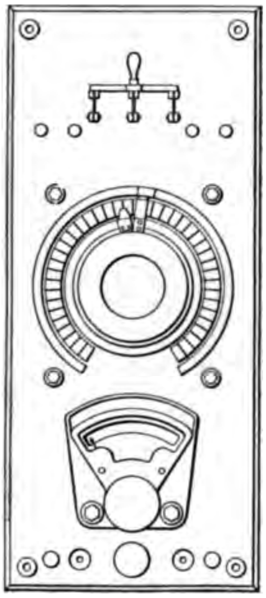


FIG. 40.

75. Westinghouse Constant-Current Incandescent System.—The series-incandescent street-lighting devices used by the Westinghouse Company are considerably different from the two previously described, in regard to the method of compensating for burned-out lamps. Ordinary 50-volt or 100-volt lamps are used. For example, on a 1,000-volt circuit, 20 50-volt or 10 100-volt lamps would be connected in series. These are preferable to the low-voltage 20-volt lamps, because they are more efficient. Moreover, the ordinary 50-volt or 100-volt lamps are cheaper. The operation of the Westinghouse device will be understood by referring to Fig. 41. *L*, *L*, *L* represent a series of

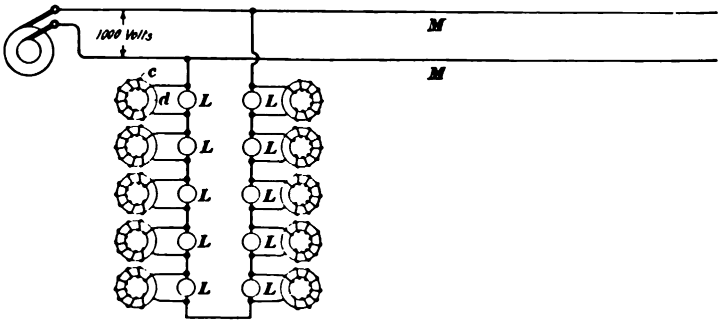


FIG. 41.

ten 100-volt lamps connected across the 1,000-volt mains M. Across the terminals of each lamp a coil c, wound on a laminated iron core d, is connected so that the coil is in shunt with the lamp under ordinary working conditions. If a lamp should break, the current must then pass through the coil. As long as the lamp is unbroken, but a very small current passes through the shunt coil; just enough current will flow to magnetize the coil sufficiently to generate a counter E. M. F. of 100 volts. When the lamp burns out, the whole current passes through the shunt coil, but as the iron in the core is worked at a point near saturation, the counter E. M. F. rises but slightly over 100 volts, although the current through the coil is very much greater than it was before the lamp broke. The coil, therefore, takes the place of the lamp and introduces into the circuit a counter E. M. F. of slightly over 100 volts to take the place of the lamp. The current remains about the same and the life of the remaining lamps is not endangered. If as many as four or five lamps are out at once, the remaining lamps become somewhat dim on account of the fact that each shunt coil introduces a little higher counter E. M. F. than the amount of the drop through the lamp that it replaces. All that is necessary to restore the circuit to its normal condition is to replace the burned-out lamps. This system has the advantage that it is automatic in its action, requiring no attention other than the replacing of old or burned-out lamps. It also has the advantage that it is not necessary to bring the circuit to the station. One end of the circuit may be attached to the main at any convenient point and the other end attached to the other main, the only essential being that the two ends shall connect to the two sides of the circuit. It has the disadvantage that if a short circuit occurs on the line,

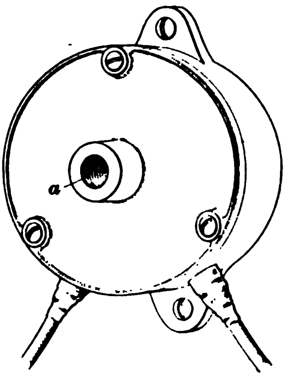


FIG. 42.

a number of the shunt coils are liable to be burned out. The shunt coils are mounted in cast-iron boxes, which also serve for the base of the bracket supporting the lamp. Fig. 42 shows the shunt-coil box. The hole *a* is tapped to receive the gas-pipe bracket, as shown in Fig. 43. Street incandescent lamps are usually provided with white enameled reflectors and are mounted about 10 to 15 feet above the ground.

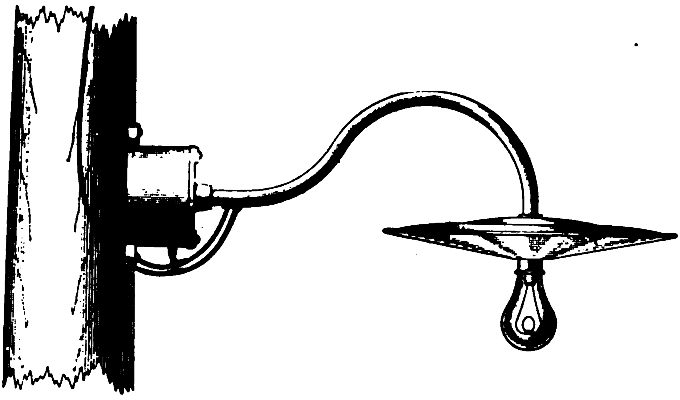


FIG. 43.

SUMMARY.

76. The methods of distribution described above represent those commonly used in practice, and it will be seen that the electrical engineer has a large number of methods from which to choose when installing a plant. Just which one is best suited to any particular case will be decided largely by the amount of the power and the distance over which it is to be transmitted. The use of multiphase systems is becoming very popular, and they are now very common whenever the power is to be transmitted for any considerable distance. Either the two-phase or three-phase systems are suitable for this work, and there is little choice between them. Direct current, using either the two-wire or three-wire system, will, no doubt, continue to be used very extensively for isolated plants or for supplying light to compact and thickly settled districts; it is simpler for this purpose than alternating current, and there is no need of using a high pressure under such circumstances, as the saving in copper would be more than offset by the additional cost of transformers.

LINE CALCULATIONS.

TWO-WIRE AND THREE-WIRE, DIRECT-CURRENT SYSTEMS.

77. The methods for calculating the size of wire required to transmit a given current over a given distance with a certain allowable drop are the same as those used for the calculation of power-transmission lines, though sometimes the formulas are put in a slightly different form so as to be more directly applicable to the subject of electric lighting.

78. The formula that is most generally applicable is the following:

$$A = \frac{21.6 \times D \times C}{e}, \qquad (5.)$$

where A = required area of cross-section of wire in circular mils;
D = distance in feet (one way) to point where current is distributed;
C = current in amperes transmitted;
e = drop in volts.

In making line calculations in connection with electric lighting, some judgment must be exercised in choosing the value of the distance D. This is not the distance to the first lamp supplied or the distance to the farthest lamp, but the distance to the center of distribution; in other words, the distance to the point at which we might imagine all the lamps to be grouped. The product of the distance D to the center of distribution and the current C is often spoken of as the ampere-feet of the circuit; hence, we may write the rule as follows:

Rule.—*The area in circular mils required for a two-wire circuit is found by multiplying the ampere-feet by **21.6** and dividing by the drop in volts.*

79. Center of Distribution.—The distance *D* to the center of distribution will be best understood by taking a few cases illustrating the point. Consider a number of lamps *l*, *l*, Fig. 44, arranged as shown and fed by the dynamo *A*. The distance from the dynamo to the first lamp is 1,000 feet, and the lamps are spaced out over a distance of 100 feet. The whole of the current would have to be transmitted through the first 1,000 feet, but from that point it would gradually fall off. We may then take the point *a* as the center of distribution, because the load is about equally distributed on each side of this point, and the distance *D* used in the formula would be 1,050 feet.

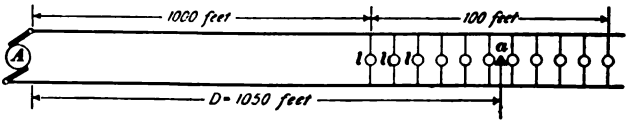


FIG. 44.

Take the case shown in Fig. 45, where the lamps are spaced evenly all the way along the line. In this case, the center of distribution *a* may be taken as at the middle, and hence the distance *D* is only one-half the length of the line from *A* to *B*. The exact location of the center of distribution becomes more difficult to determine when the load is unevenly spaced or distributed, but in most cases it can be located close enough for practical purposes by laying out the system and noting carefully the loads on the different circuits.

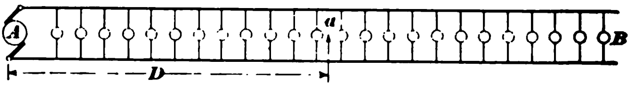


FIG. 45.

80. Current Estimation.—The current can be readily determined when the nature of the load is known. The general practice is to allow $\frac{1}{2}$ ampere for each 16-candlepower lamp and 1 ampere for a 32-candlepower lamp on 110-volt circuits. It might be well to mention at this point that some prefer to make calculations for lighting circuits by using *lamp-feet* instead of ampere-feet. The number of **lamp-feet** is the product of the number of 16-candlepower lamps to be supplied and the distance to the center of distribution. When this term is used, it always implies the use of 16-candlepower lamps; if any 32-candlepower lamps are operated, each lamp must be counted as two 16-candlepower, etc. If lamp-feet are used, the formula becomes

$$A = \frac{10.8 \times D \times N}{e}, \qquad (6.)$$

where A = area in circular mils;
D = distance in feet one way to center of distribution;
N = number of lamps (expressed in terms of 16-candlepower lamps);
e = drop in volts.

Rule.—*To determine the area of cross-section for a two-wire 110-volt circuit, multiply the lamp-feet by 10.8 and divide by the drop in volts.*

81. This rule is here given because it is frequently used. Formula **5** is, however, much to be preferred, because formula **6** assumes that each lamp takes $\frac{1}{2}$ ampere, and this may or may not be the case. Formula **5** is applicable to any case because the current is used in it, and this current is determined from a knowledge of the devices to be operated. The use of these formulas will be understood from the following examples, applying them to the calculations of lines for an ordinary two-wire lighting system. We will first take the simple case shown in Fig. 44.

EXAMPLE 1.—A dynamo A, Fig. 44, delivers current at 110 volts to 50 lamps distributed as shown about a as a center. The drop must not exceed 10 volts. Find the size of wire required.

Solution.—The distance to the center of distribution is here 1,050 feet, as already explained. The current will be 25 amperes, because each lamp will take ½ ampere. Using formula **5**, we have

$$A = \frac{21.6 \times 1,050 \times 25}{10} = 56,700 \text{ cir. mils. Ans.}$$

A No. 3 B. & S. wire would likely be used.

Example 2.—A dynamo *A*, Fig. 46, supplies current through the feeders *b*, *c* to the feeding-in point *a*. From this point lamps are supplied by means of the mains *d*, *e* and *f*, *g*. The number of 16-candle-power lamps and the various distances are shown in the figure. The total drop in voltage from the dynamo to the last lamps must not exceed 15 volts, of which 13 volts is to be in the feeders and 2 volts in the mains; required, (*a*) the cross-section and gauge number of the feeders *b*, *c*; (*b*) the cross-section and nearest gauge number of the mains *d*, *e*; (*c*) the cross-section and nearest gauge number of the mains *f*, *g*.

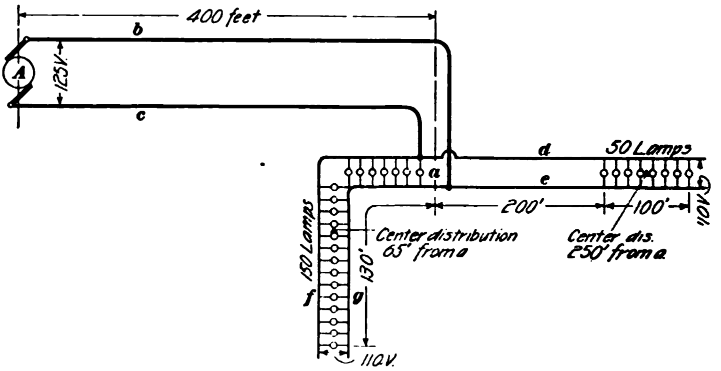


Fig. 46.

Solution.— 150 lamps will require 75 amperes.
50 lamps will require 25 amperes.

Total current 100 amperes.

(*a*) We are allowed a drop of 13 volts in the feeders and a drop of 2 volts in the mains. No current is taken from the feeders at any intermediate point; hence, the distance *D* from the dynamo to the center of distribution *a* will be taken the same as the actual distance, i. e., 400 feet. Using formula **5**, we have, then, for the feeders

$$A = \frac{21.6 \times 400 \times 100}{13} = 66,461 \text{ cir. mils.}$$

This would call for a No. 2 B. & S. wire. Ans.

(*b*) The current in the mains *d*, *e* will be 25 amperes. The distance from *a* to the center of distribution will be $200 + \frac{100}{2} = 250$ feet, because the lamps are spaced evenly along the last 100 feet. The drop in the mains is not to exceed 2 volts; hence, we have

$$A = \frac{21.6 \times 250 \times 25}{2} = 67{,}500 \text{ cir. mils. Ans.}$$

This also would call for a No. 2 B. & S. wire. No. 2 B. & S. wire is a little smaller than the cross-section called for, but it would probably be used, as the increased drop caused by doing so would be very small.

(*c*) The current supplied through mains *f*, *g* is 75 amperes. Here the load is uniformly distributed along the mains, and the distance to the center of distribution is $\frac{130}{2} = 65$ feet. The drop is 2 volts. We have, then,

$$A = \frac{21.6 \times 65 \times 75}{2} = 52{,}650 \text{ cir. mils.}$$

This would call for a No. 3 B. & S. wire. Ans.

It will be noticed in this example that although the mains carry a smaller current over a shorter distance than the feeders, they work out about the same size. This is because of the large drop allowed in the feeders compared with that in the mains.

EXAMPLE 3.—Fig. 47 shows a three-wire distributing system. The dynamos *A*, *B* supply current through feeders to the junction box *J*. From this point mains are carried to the buildings where light is to be supplied. In this case, the conductors marked mains are sometimes called subfeeders, because they are really branches of the main feeder and no branches are taken off between the junction box and the end of these lines. In this case, the total drop from the dynamo to the lamps is not to exceed 10 per cent. of the lamp voltage, and the pressure at the lamps is to be 110 volts. (*a*) Calculate the size of the feeders *C*. (*b*) Calculate the size of the mains *D*. (*c*) Calculate the size of the mains *E*. The calculation of the size of wires required for the house wiring will not be taken up here, as it belongs to interior wiring and we are only concerned for the present with the outside distributing wires. The pressure at the dynamo will be $110 + 110 \times .1 = 121$ volts. Of the total drop of 10 per cent. we will allow 1.5 per cent. in the house wiring, 3.5 per cent. in the mains, and the remaining 5 per cent. in the feeders, as indicated in the figure.

SOLUTION.—In calculating the size of the conductors, we will consider the system as a two-wire system, the pressure between the two outside wires at the lamps being $2 \times 110 = 220$ volts and at the dynamo $2 \times 121 = 242$ volts. We will obtain the size of the outside wires, and a neutral wire one-half the size of the outside wires should be amply sufficient. The total current supplied may be obtained as follows:

(*a*) Each pair of lamps on a 220-volt three-wire system requires $\frac{1}{4}$ ampere; hence, current in line D will be $\frac{100}{4} = 25$ amperes. Current in E will be $\frac{400}{4} = 100$ amperes. Total current in the feeders C will be 125 amperes. The total drop between the outside wires is $242 - 220 = 22$ volts. The drop in the main feeders is to be 5 per cent. of the lamp voltage, or $220 \times .05 = 11$, or 5.5 volts on each side. The distance to the center of distribution is 700 feet; hence,

$$A = \frac{21.6 \times 700 \times 125}{11} = 171{,}818 \text{ cir. mils. Ans.}$$

This would call for a No. 000 B. & S. wire for the outside wires from the dynamo up to the point J. The neutral wire could be made about No. 1.

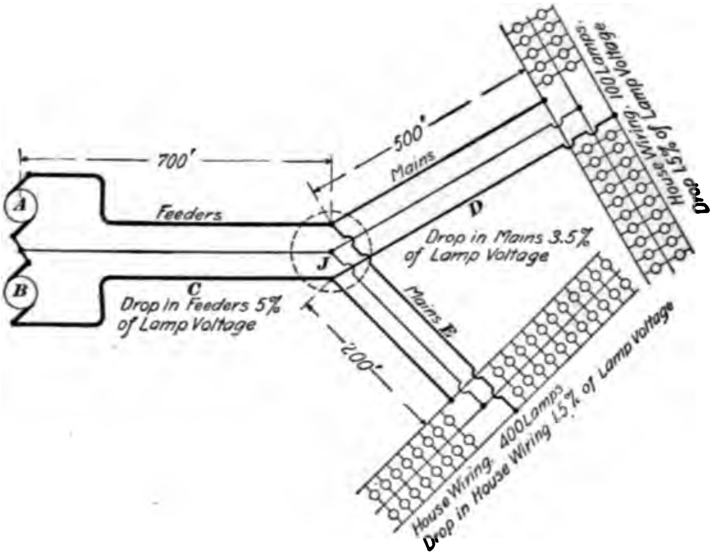

700′
500′
Mains
A
B
Feeders
D
J
C
Drop in Feeders 5% of Lamp Voltage
Drop in Mains 3.5% of Lamp Voltage
Mains E
200′
House Wiring. 100 Lamps.
Drop 1.5% of Lamp Voltage
House Wiring. 400 Lamps.
Drop in House Wiring 1.5% of Lamp Voltage

FIG. 47.

(*b*) The drop in mains D or E will be $220 \times .035 = 7.7$ volts. The area of mains D will be

$$A = \frac{21.6 \times 500 \times 25}{7.7} = 35{,}065 \text{ cir. mils. Ans.}$$

This would require a No. 5 wire, and a No. 8 or 9 would be sufficient for the neutral.

(*c*) The area of mains E will be

$$A = \frac{21.6 \times 200 \times 100}{7.7} = 56{,}104 \text{ cir. mils, nearly. Ans.}$$

A No. 3 B. & S. wire would probably be used for the outside wires and a No. 6 for the neutral.

CALCULATIONS FOR ALTERNATING-CURRENT LINES.

82. A load that consists wholly of lamps possesses very little self-induction, and for ordinary lighting systems, where the distances are short, it is usual to make the calculations for lines carrying alternating current in the same way as already described for the direct-current system. This assumes the power factor to be 1, which is not exactly true. If greater accuracy is required, formulas taking into consideration the power factor should be used. After the primary current has been determined and the distance to the center of distribution is known, the size of the primary line wire may be worked out. The power supplied over the line must be slightly greater than that supplied to the lamps, on account of the loss in the transformers. This loss will depend, of course, on the efficiency of the transformer; some of the older styles had a low efficiency, but very little power is wasted in transformers of modern make. Table III gives the average efficiency at full load, as attained by good transformers.

TABLE III.

EFFICIENCY OF TRANSFORMERS.

Output. Watts.	Efficiency. Per cent.	Output. Watts.	Efficiency. Per cent.
1,000	94.8	7,000	96.80
2,000	95.7	8,000	96.85
3,000	96.2	9,000	96.90
4,000	96.4	10,000	96.95
5,000	96.6	15,000	97.20
6,000	96.7		

83. In order to illustrate the calculation of primary mains, we will consider the case shown in Fig. 48.

Example.—Current is supplied to the transformers *T* by means of the primary mains *A*, *B*. The voltage at the lamps is to be 104 volts (a common value used in connection with alternating-current lighting work). A total of 1,000 16-candlepower lamps is to be operated from the secondaries. The voltage at the transformer is to be 2,000 volts at full load and the drop in the primary mains 200 volts, thus making the voltage at the alternator 2,200 volts at full load. The loss in the secondary wiring at full load must not exceed 2 volts, and the lamps require 3.5 watts per candlepower. The average efficiency of the transformers may be taken at 96 per cent. Required the cross-section of the primary wires.

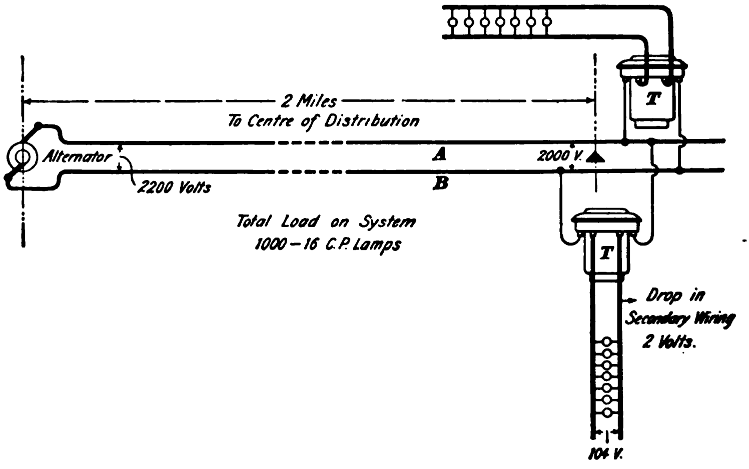


FIG. 48.

SOLUTION.—Each lamp requires 16 × 3.5 = 56 watts, and 1,000 lamps would call for 56,000 watts in the secondary circuit at the lamps. The total secondary current would be $\frac{56000}{104}$ amperes, and since there is a drop of 2 volts in the secondary wiring, the number of watts lost will be $\frac{56000}{104} \times 2$, and the total watts delivered by the secondary must be $56,000 + \frac{56000}{104} \times 2 = 57,077$, nearly. The watts delivered to the primaries would be $\frac{57,077}{.96} = 59,455$, and since the primary voltage of the transformers is 2,000, the primary current will be $\frac{59455}{2000} = 29.73$ amperes, nearly. Having determined the primary current, we can now calculate the size of the line. The distance in this case is 2 miles, or 10,560 feet, and the drop 200 volts. We may now use formula **5**, considering the problem the same as for a continuous-current circuit.

$$A = \frac{21.6 \times 10,560 \times 29.73}{200} = 33,906, \text{ approximately. } \textbf{Ans.}$$

This would call for a No. 5 B. & S. wire.

84. For rough calculations of the primary current on 1,000-volt and 2,000-volt primary mains, the following allowance per lamp may be used:

TABLE IV.

CURRENT ALLOWANCE PER LAMP.

Candlepower of Lamp.	1,000 Volts Primary Pressure. Current per Lamp.	2,000 Volts Primary Pressure. Current per Lamp.
10	.035	.0175
16	.050	.0250
32	.100	.0500
50	.150	.0750

For example, if 800 16-candlepower lamps were operated on a 2,000-volt circuit, the primary current would be about 800 × .025 = 20 amperes. This, of course, does not give the current exactly, because to obtain this the efficiency of the transformers and the lamps should be known, but it affords a ready means of getting at the current approximately when preliminary calculations are being made. In many cases, the more refined calculations would not change the size of the wire in any event, because the wire selected must be taken as one of the standard sizes, and this in most cases is not the same as the calculated size.

85. In case the lamps are operated on two-phase or three-phase systems, the watts to be supplied by the alternator can easily be obtained when the watts per lamp and the efficiency of the transformers are known. After the watts have been determined, the formulas given in *Electric Transmission*, Part 1, may be used to calculate the size of the wire.

EXAMPLE.— 1,000 16-candlepower, 60-watt lamps are to be operated on a three-phase system at a point 16,000 feet from the station. The voltage at the transformers is to be 2,000, and 10 per cent. of the power delivered is to be allowed as loss in the line. The transformer efficiency is 96 per cent., and 2 per cent. of the power delivered at the lamps is lost in the secondary wiring. Find the necessary cross-section of the line wires.

SOLUTION.—Power supplied to lamps = 1,000 × 60 = 60,000 watts. Power delivered by secondaries = 60,000 + .02 × 60,000 = 61,200. Power supplied to transformers from primary lines = $\frac{61,200}{.96}$ = 63,750 watts.

Referring to *Electric Transmission*, Part 1, we find that the circular mils are given by the formula

$$\text{Circular mils} = \frac{D \times W}{P \times E_2^2} \times t.$$

In this case, $D = 16,000$; $E_2 = 2,000$; $P = 10$. Since this is to be a three-phase system and the load consists wholly of lights, the constant t may be taken as 1,200.

Hence,

$$\text{Circular mils} = \frac{16,000 \times 63,750}{10 \times 2,000 \times 2,000} \times 1,200 = 30,600. \quad \text{Ans.}$$

This is between a No. 5 and a No. 6 B. & S. wire. The No. 5 wire would most likely be used.

86. When the total watts to be delivered are known, the current in the line and the drop in voltage may be estimated by means of the formulas given in *Electric Transmission*, Part 1. The percentage drop in voltage may be considerably greater than the percentage loss in power if the lines are long and spread a considerable distance apart, because under such circumstances the self-induction of the lines would have considerable effect. It is customary when making calculations with regard to ordinary single-phase lighting circuits that are not of great length to use the rules given for direct current. This is especially true with regard to the secondary distributing system, and in nearly all cases will give results sufficiently accurate for practical purposes.

THE LIGHTING STATION.

87. The design of the central station for an electric-lighting plant involves a great many considerations that depend on the system of distribution adopted. The choice of the system itself, as to whether the direct or alternating current should be used, is dependent on the area of the territory to be lighted and on the distance between the centers of generation and distribution. Thus, for small districts in which the lighting is dense and in which the central station can be placed approximately in the center of the area illuminated, the two-wire, direct-current, low-pressure system is the one most suitable. It has been found, however, that such a system is no longer economical when the mean length of the feeders becomes greater than 300 yards.

By the Edison three-wire system, the distribution of direct-current, low-pressure supply may be economically conducted for a feeder length of from one-half to three-quarters of a mile. The five-wire system allows of a mean feeder length of one mile. Beyond this distance direct-current systems are too costly, and, therefore, the alternating-current system is used.

88. The Location of the Central Station.—Since nearly all incandescent-lighting stations use the constant-potential or parallel system of distribution, the location of the station with reference to the district to be supplied is of the highest importance and should never be decided on until all conditions entering into the problem have been carefully weighed; for when this system is used the question of conducting heavy currents makes the cost of the conductor a figure that must be kept as low as possible, and this can only be attained by making all distances as short as possible. This would mean that the central station should be placed in the center of the system to be served. Very often it is found that, owing to the questions of coal and water supply, the price of real estate, or other local conditions, the central station cannot be placed in the center of the system, and that the loss in conductor copper is offset by other advantages. These are points that the designing engineer considers after studying the map of the area to be served and the estimates of the probable supply.

In general, however, it will be observed that the central station in parallel distribution forms very nearly the electrical center of gravity of the system. The present tendency in large cities seems to be towards the consolidation of the generating plant in one large central station located at some point where the fuel and water supply is good. This is the natural outcome of high-tension transmission. These stations are provided with alternators of large output that supply current at high pressure to various substations located near the points of distribution. By utilizing this high-pressure transmission scheme, it becomes unnecessary to have the plant located near the point where the current is used. Such an arrangement involves more complication than where the current is supplied directly from the generating station, but for large cities it is, nevertheless, found to be advantageous.

89. The Boilers.—The greatest demand for current from a central station supplying lighting circuits occurs at stated hours, during which time the boilers are usually called upon for their full steam capacity. Before and after this time the demand for current is very much less, and the boilers are, therefore, not often worked to their full capacity. Unless they are used continuously, it is evident that the lighting and firing up of the several boilers for only short periods during the evening produces an immense waste of heat from radiation and conduction, which takes place as they cool down after having been thrown out of use. Such losses are, of course, increased when there are larger masses of brickwork in direct contact with the fuel which must be heated up. For this reason, internally fired boilers, such as the marine boilers or the Lancashire type, are often used, though the latter has the objectionable feature of requiring much floor space. Owing to this cause, water-tube boilers, of which the well-known Babcock & Wilcox is a good example, are very generally used in electric-lighting stations.

90. The Engines.—In the selection of engines, the choice lies between direct-coupled engines and those driving dynamos by belting or rope gear.

The engine built for direct coupling to dynamos must necessarily have the speed required to run the dynamo. This speed is a relatively high one for engines, even where the dynamo is very large, and until quite recently such engines were not numerous. At present, however, high-speed engines of high grade are much used, and the modern central station is mainly equipped with direct-coupled machines. These are particularly adapted to stations where space is limited. Where this is not the case, many plants drive their dynamos in groups, either from the engine flywheel or by means of belting.

DYNAMOS FOR INCANDESCENT LIGHTING.

91. The type of dynamo used for operating a lighting system will depend on the method of distribution adopted. The construction of the dynamo will also depend to some extent on the method used for driving it; i. e., on whether it is driven by means of a belt or coupled directly to the steam engine or waterwheel. We will consider, briefly, a few of the different types used in order to point out some of their distinguishing features.

DIRECT-CURRENT DYNAMOS.

92. Belt-Driven Dynamos.—Dynamos used for operating incandescent lamps on the two-wire or three-wire systems are almost invariably compound-wound. Shunt-wound machines were used some years ago for this purpose, but the compound-wound machine is much better, since it keeps the voltage at the right value automatically. Usually the machines are overcompounded, so as to give a rise in voltage from no load to full load corresponding to the drop in the line, and thus keeping the pressure at the lamps con-

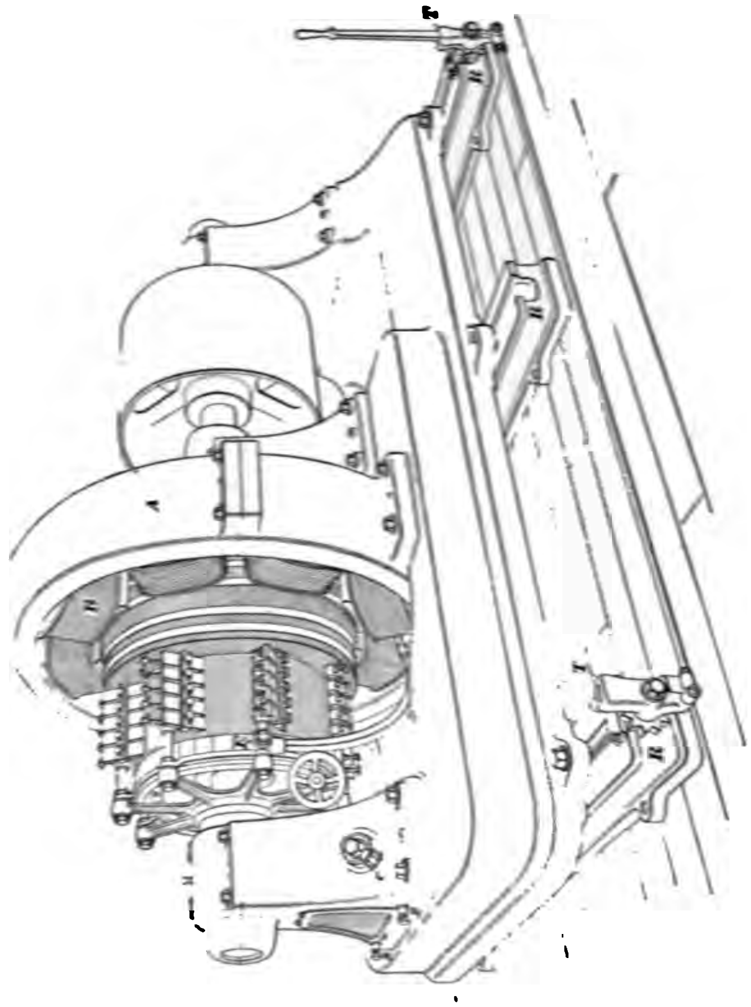


FIG. 40.

stant. Modern dynamos used for this purpose are nearly always of the multipolar type. Two-pole machines were formerly much used, but these have given place to the multipolar type. All the dynamos used for any kind of work may be divided into two classes, according to the method used for driving them, i. e., **belt driven** and **direct connected.**

Fig. 49 shows a Wood eight-pole compound-wound dynamo as used for lighting on a 110-volt, two-wire system, or 110–220-volt, three-wire system. This machine is mounted on rails *R*, so that the tension of the belt may be adjusted by sliding the machine by means of the ratchets *T*, *T*. The magnet yoke *A* is circular and is provided with eight inwardly projecting poles, each of which is provided with a field spool *B*. Each of these spools is provided with two windings: a shunt winding, consisting of comparatively fine wire, and a series winding, usually of copper strip or heavy wire, capable of carrying the whole current furnished by the machine. One terminal of the machine is shown at *e*, and the other is on the opposite side of the pedestal. From these two terminals the positive and negative leads are carried to the switchboard. The connections for the shunt winding and the shunt-field rheostat are made by means of the small terminals *s*, *s*. When two or more machines are run in multiple, a third main connection is led from the terminal *E* to the equalizing bar on the switchboard. The machine shown has a capacity of 260 kilowatts, runs at 500 revolutions per minute, and weighs a little over 9 tons complete. Belt-driven machines are smaller and cheaper for the same output than direct-connected machines, because they run at a higher speed. Notwithstanding this fact, the direct-connected type is becoming very popular, especially in places where economy of space and compact arrangement are desired.

93. Direct-Connected Dynamos.—By using direct-driven machines, all wear and tear on belts is avoided and a large saving in space effected. Fig. 50 shows a compound-wound dynamo made by the Fort Wayne Electric Works direct connected to a high-speed engine, and is a

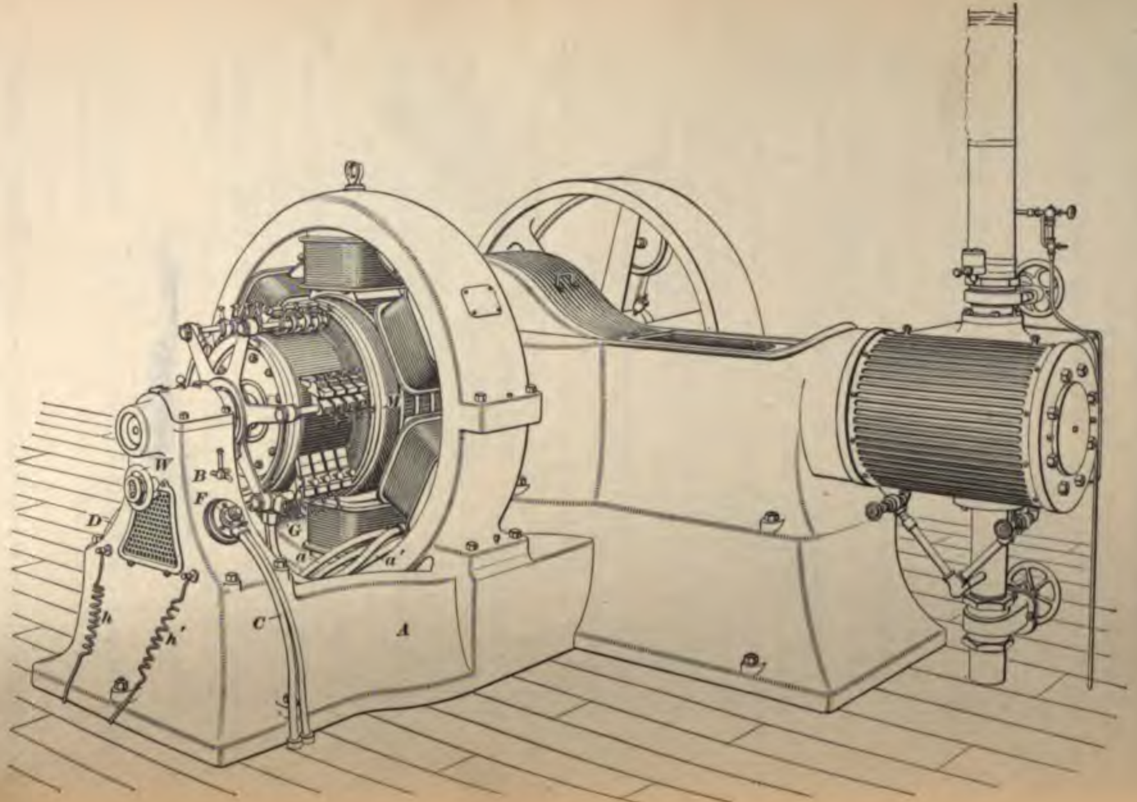
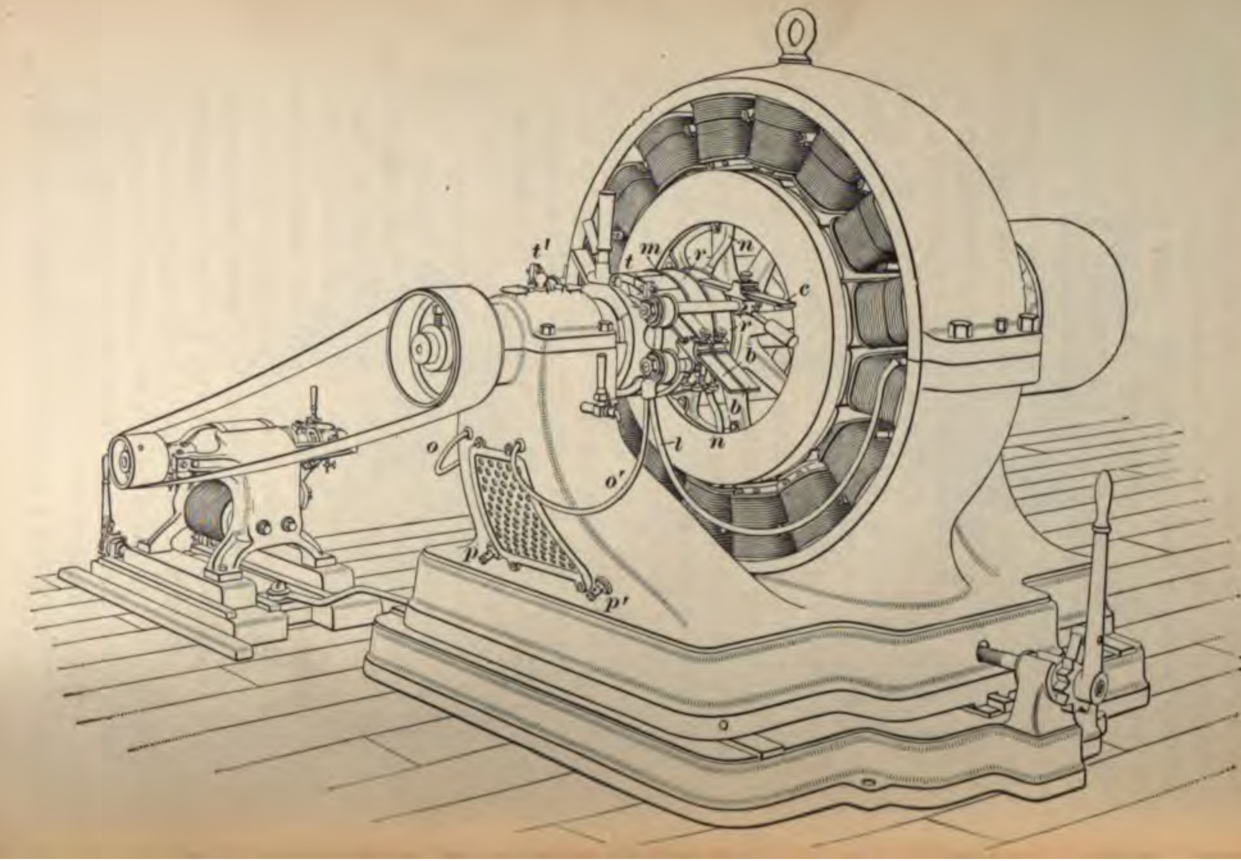


FIG.

typical example of a multipolar direct-driven set. Such a combination is largely used for isolated plants and also for central stations of moderate size. For larger stations it is customary to use slow-speed engines of the Corliss type direct connected to large multipolar dynamos. The dynamo, Fig. 50, is mounted upon an extension bedplate *A* provided with an outboard bearing *B*. This machine is compound-wound, *a*, *a'* being the leads connecting to the terminals of the series coils; *C* and *D* are the mains running to the switchboard; the leads from the brushes are attached to the connection boards, one of which is shown at *F*. The terminal for the equalizing wire is shown at *G*. The small leads *h*, *h'* are connected to the shunt winding and are led to the switchboard so that the field rheostat may be connected in series with the shunt field. The hand wheels shown at *W* are for adjusting the brushes to the non-sparking point and clamping them in position. Nearly all modern dynamos use carbon brushes, except, perhaps, a few machines where the voltage is low and the current correspondingly large. In order to use carbon brushes without overheating at the commutator, it is necessary to allow ample contact surface between brushes and commutator. Usually about 1 square inch of brush contact surface is necessary for every 30 to 40 amperes collected, and in the case of low-tension incandescent-lighting dynamos this calls for a large commutator. Notwithstanding the fact that carbon brushes require a much larger and more expensive commutator than copper brushes, they operate so much better that the increased first cost is warranted. The carbon brushes run with much less sparking and do not cut the commutator, as copper brushes are apt to do, unless they are very carefully looked after. Most incandescent dynamos have bar-wound armatures, i. e., the conductors on the armatures are in the shape of copper bars rather than wires, because a large cross-section of conductor is necessary in order to carry the current. The ends of these bars leading to the commutator are seen at *M*, Fig. 50. The machine here shown has a capacity of 75 kilowatts and runs


t'
t
m
r
n
c
r'
b
b
n
l
o
o'
p
p'

at a speed of 275 revolutions per minute. The speed of the larger sizes of direct-connected machine is correspondingly lower, and in case they are direct connected to large, slow-speed Corliss engines, the speed is usually from 75 to 100 revolutions per minute.

ALTERNATING-CURRENT DYNAMOS.

94. Alternators may be constructed with either the armature or field as the revolving member, or they may be made without any revolving wire whatever, the only revolving part being a mass of iron, called an **inductor.** We may have, then, a comparatively large number of different types of alternators to choose from as compared with direct-current machines. When alternating current first came into use for lighting work, machines with revolving armature and stationary field were the only kind used, and these machines were almost invariably belt driven. The frequency employed was usually from 125 to 133 cycles per second, and the machines were often provided with a compound winding supplied through a rectifier. Practically all the alternators in use are wound to give a constant potential. The shunt winding of the ordinary compound-wound continuous-current dynamo is replaced by a separately excited winding, which is supplied from a small direct-current exciter. Again, the variety of alternators is increased by the various number of phases that are in common use.

95. Belt-Driven Alternators.—Fig. 51 shows a typical belt-driven alternator as used for lighting work. This particular machine is of the Wood type made by the Fort Wayne Electric Works, and it illustrates the general characteristics of a type of machine that has been and still is largely used for incandescent-lighting work. The Westinghouse and General Electric alternators of this class are very similar in general appearance to the one shown. This is a single-phase machine of 150 kilowatts capacity delivering current at 60 cycles per second. The alternator is provided with only two collector rings r, r because it generates single-phase current. Each ring is provided with a brush c. The rectifier is shown at m, and by means of it the current sent through the series field winding is made unidirectional; b, b is a pair of the rectifier brushes and there is a similar pair, not shown, on the opposite side of the rectifier. One of the leads connecting to the series field is shown at l, and there is a similar one on the other side of the machine. The terminals of the armature winding leading to the collector rings and rectifier are shown at n, n. The terminals of the machine are t, t', and from these the main wires are led to the switchboard. The two leads o, o' lead from the terminals of the series coil to the shunt used in connection with the compound coils. This shunt is housed in the bearing pedestal. The exciter is here shown belted to a pulley on the end of the alternator armature shaft. In many cases the exciter is driven separately. The binding posts p, p' are the terminals of the separately excited field coils. The whole machine is mounted on rails so that the tension on the belt may be adjusted. The ordinary incandescent-lighting alternator of the type shown is usually wound for either 1,100 volts or 2,200 volts, as these pressures are high enough for economical distribution unless the distances are longer than are usually met with in the common run of towns or medium-sized cities.

96. Fig. 52 shows a General Electric alternator of the evolving-field belt-driven type. This machine is of 300 kilowatts capacity and is wound to deliver three-phase cur-ents at a frequency of 60 cycles. The revolving field is een at A, but a better idea as to the construction of the achine will be obtained by referring to Fig. 53. The evolving field consists of a steel ring B supported by the ider c c. The ring B carries the laminated pole pieces D, hich are dovetailed into the ring as shown at e. In the rger machines the pole pieces are bolted to the ring. Each le piece is provided with a field coil d, which, in the larger

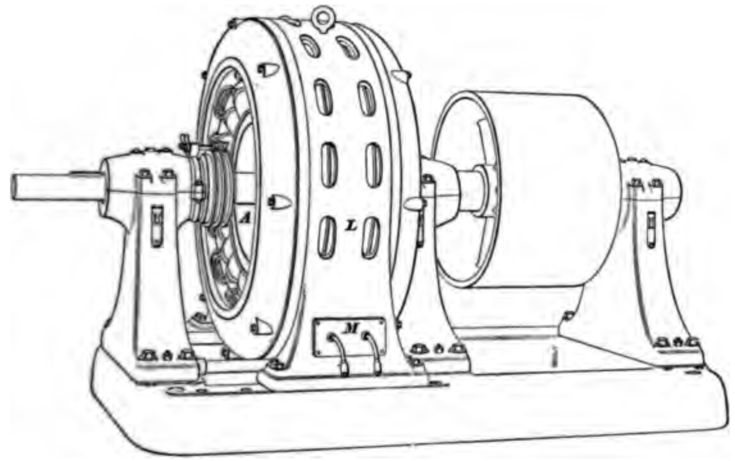


FIG. 52.

machines, is wound with copper strip placed on edge. These coils are connected in series and their terminals brought to

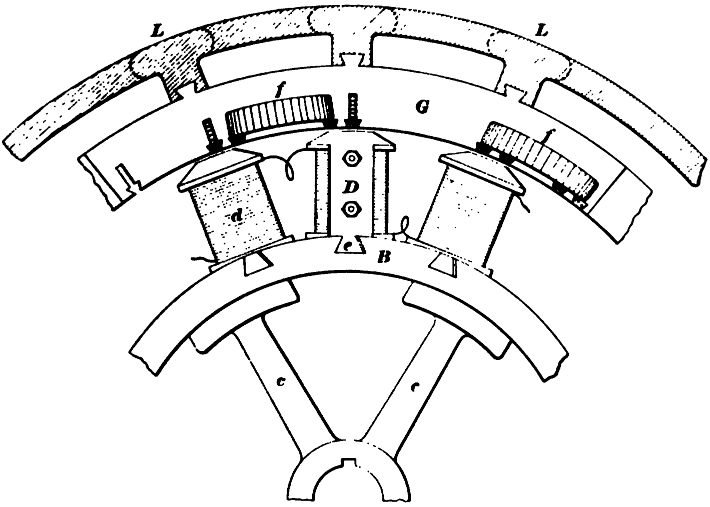


FIG. 53.

collector rings mounted on the shaft. By means of these rings the exciting current is led into the field. The stationary armature windings *f*, *f* (in this case shown for a single-phase

548438

the core together and also to carry the magnetism. The path of the magnetic flux is indicated by the dotted line *1-2-3-4*, and when the inductor revolves, the lines of force sweep across the stationary coils and thus set up the required E. M. F. This machine has the advantage of having no moving wire about it, but machines of the revolving-field type, such as shown in Fig. 52, have the advantage of using small field coils that are easily repaired or replaced in case anything goes wrong with them. A number of other types of inductor alternator are in use. The Westinghouse machine of this type is similar to the one just described and operates on the same principle, the chief difference being that there is only one armature instead of two, i. e., the double construction shown in Fig. 55 is not used. The same is true with regard to the Warren alternator.

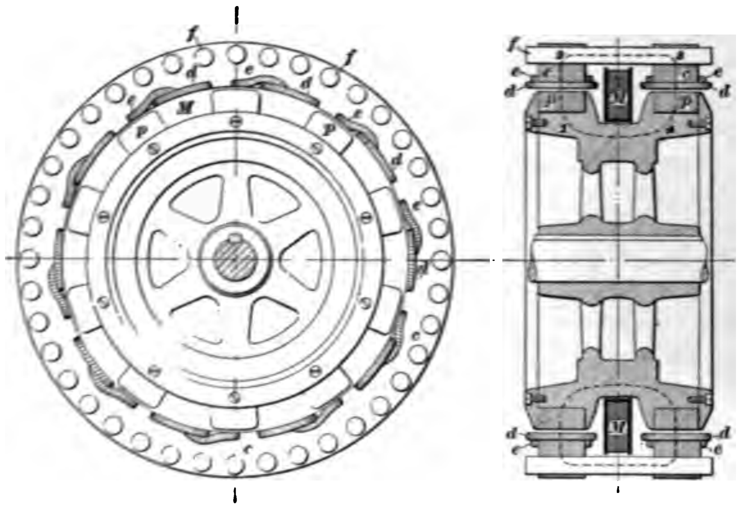


FIG. 55.

98. Direct-Connected Alternators.—Alternators direct connected to waterwheels or steam engines are now quite common in connection with electric-lighting work. Their construction is essentially the same as that of belted whole armature structure is arranged so that it may be slid along on the base so as to give access to the field and armature coils.

97. Inductor Alternator.—Some makers have gone a step further and construct alternators without any moving wire whatever. These machines are of the **inductor** type, so called because both the armature and field-exciting coils are stationary and the magnetism passing through the armature coils is made to vary by revolving a mass of iron called an inductor. One of the most widely used of these types is the Stanley machine. These are made for several different outputs and Fig. 54 represents one of the larger sizes. In this view the two halves *A*, *A* of the stationary armature are shown drawn back so as to allow access to the coils. When the machine is in operation, these halves are bolted together by means of bolts passing through the lugs *a*, *a*. The machine is double, there being two laminated cores *c*, *c*, in the slots of which the coils *d*, *e* are mounted (see also Fig. 55). It will be noticed that the coils marked *d* are placed midway between those marked *e*, one set of coils overlapping the latter. The result of this arrangement is that when half the conductors of one set of coils is directly under the poles, the conductors of the other set are out from under the poles; hence, when the current in one set is at its maximum value, the current in the other set is at its minimum value, thus making this particular machine deliver two currents that differ in phase by 90°. The machines can also be built to supply single-phase or three-phase currents, if desired. The revolving inductor is shown at *I*, Fig. 54, surrounded by the magnetizing coil *M*. All the polar projections *p* on one side of the coil are of the same polarity, and there is a similar set of opposite polarity on the other side of the coil. The construction will be understood by referring to Fig. 55, which shows an end view and section of a large Stanley machine, the different parts being lettered to correspond with those shown in Fig. 54. The holes *f*, *f* in the armature-core stampings receive heavy iron bars that serve to hold

99. General Remarks.—From the foregoing it will be seen that for a given installation there is a wide variety of generating apparatus from which to choose. The question as to whether alternating or direct current shall be used is, in most cases, decided by the distance over which the current is to be transmitted; and the question as to whether direct-connected or belted machines shall be used depends on the question of first cost and the space available. Direct-connected machines cost somewhat more than belted ones of the same output, but, as the first cost and wear and tear on belts is done away with, and as the wear on the slow-speed machine is small, it may prove that the more expensive direct-connected machine is the cheaper in the long run. Again, in places where space is valuable it may be almost absolutely necessary to use direct-connected units. This is very frequently the case in city-lighting plants and in isolated plants in large buildings. In making the choice of a dynamo, then, for any particular plant, it is important that the surrounding conditions be taken into careful consideration, so that the machine that will do its work most efficiently and with the least expense for maintenance will be selected. The tendency is strongly towards the use of direct connected machines.

ELECTRIC LIGHTING.

(PART 2.)

STATION APPLIANCES.

1. In addition to the dynamo, the equipment of an incandescent-lighting station comprises a number of appliances that are necessary for the operation of the station. These instruments are intended for the control or protection of the various machines and circuits, and they are usually grouped together and connected up on the **switchboard.** The arrangement and construction of the switchboard itself will be taken up later; for the present, we will consider briefly some of the more important appliances themselves.

The kind of instruments used in connection with the operation of the plant will depend, to a great extent, on whether direct or alternating current is used, and on whether this current is supplied at high pressure or low pressure. The appliances suitable for a 110-volt direct-current installation would not be suitable for a 2,000-volt alternating-current system. Among the more important station appliances to be considered are the following: *switches*, *bus-bars*, *voltmeters* and *ammeters*, *fuses*, *circuit-breakers*, *rheostats*, *ground detectors*, and *lightning arresters*.

SWITCHES AND BUS-BARS.

2. Low-Tension Switches.—Switches are used to disconnect a circuit or dynamo whenever desired. If the current to be handled is large, the switch must be of massive

For notice of the copyright, see page immediately following the title page.

construction. For ordinary work, where the pressure does not exceed 200 or 300 volts, plain knife switches are used. Fig. 1 shows a typical two-pole knife switch. Most of these switches are mounted directly on the slate or marble of which the switchboard is constructed, and connections are made to them by means of studs running through to the back. When the switch is opened, connection is broken between the clips *1* and *2*, *3* and *4*, thus opening both sides

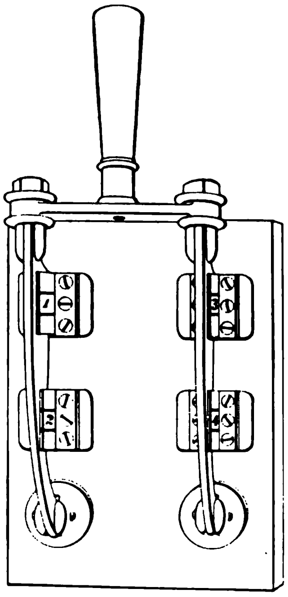


FIG. 1.

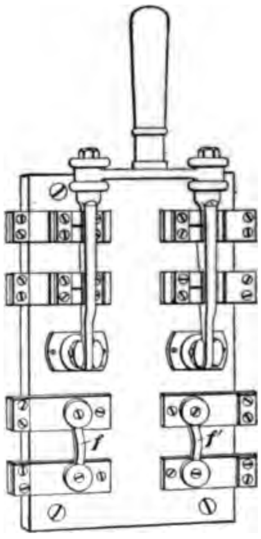


FIG. 2.

of the circuit. Knife switches should be substantially constructed and should have a contact surface at the clips of at least 1 square inch for every 80 to 100 amperes. The blades should be made of good conducting material, preferably of drawn copper, and the clips should be stiff enough to give a good, firm contact. A brass rich in copper is frequently used for such switches, but if this is done, the switches should be made to give a larger contact surface than if pure copper blades were used. For pure copper, the blades should have a cross-sectional area of about 1 square inch for every 1,000 amperes carried. Fig. 2 shows a front-connected switch provided with fuses *f*, *f'*, and Fig. 3 shows a triple-pole switch as mounted on a switchboard and arranged for back connection. This last style is often used where compound dynamos are operated in multiple, the middle blade making the connection to the equalizing bar. Triple-pole switches are also used in connection with three-phase installations. Knife switches should always be mounted with the handle up, so that the blades are swung down in order to open the switch. This is done in accordance with a rule of the Fire Underwriters, which requires switches to be so placed that when opened they will not tend to fall closed of their own accord, but will, on the contrary, tend to remain open. All switch bases should be of incombustible material, such as marble, slate, or porcelain.

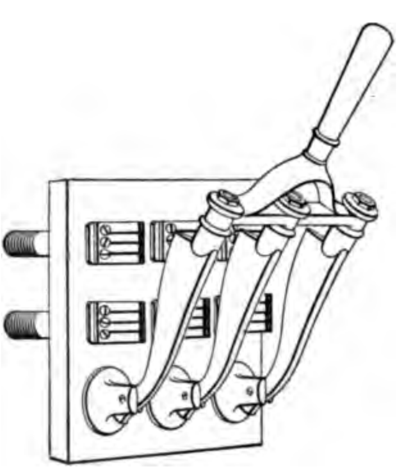


FIG. 3.

3. High-Tension Switches.—These switches are used in connection with alternating-current work where the pressure is high and where ordinary switches would not be capable of breaking the arc. A great many types of high-tension switches have been introduced, and their design depends to a large extent on the voltage to be handled. Figs. 4 and 5 show a style of quick-break switch that has proved very successful both in lighting and street-railway work. It is simple in construction, breaks the arc very quickly, and operates well on circuits where the pressure does not exceed about 3,000 volts. The figures show the single-pole type, but it is made also for two or three poles, as may be desired. Fig. 4 shows the switch closed and Fig. 5 shows it partly opened. The switch blade, which is

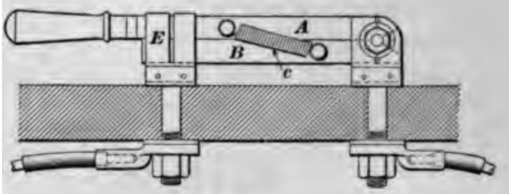


FIG. 4.

of drawn copper, is made in halves *A*, *B*, which are connected by two springs *c*, one on each side of the blade. When the handle is pulled out, the half *A* leaves the clip *E*

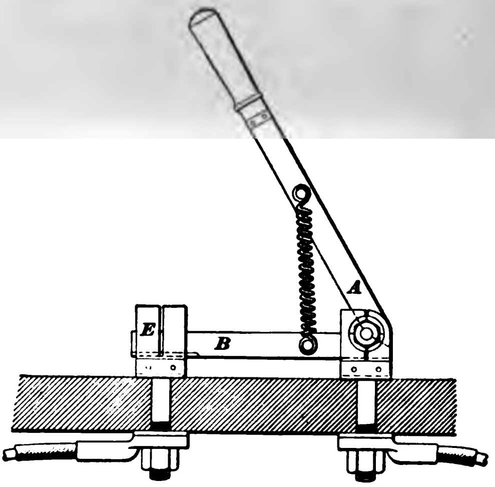


FIG. 5.

and thus stretches the springs. When the bottom blade flies out, it leaves clip *E* very quickly, owing to the action of the springs, thus drawing out the arc and breaking it almost instantaneously. The main switch on the board shown in Fig. 60 is very similar in principle. When the blade is pulled out, a follower maintains contact until the blade has been pulled back a considerable distance, when it flies back and thus breaks the arc. When knife switches are used on high-tension boards, it is a common practice to separate the blades by marble barriers, as shown in Fig. 60, in order to prevent the arc jumping from one blade to the other.

4. Fig. 6 shows the same style switch as Fig. 4, but it is mounted so as to be capable of handling higher pressures. The switch is constructed so as to give a long, quick break, and is mounted on insulators *1*, *2*, *3*, *4*. These are made of hard rubber or similar material and are grooved so as to make the leakage path from the switch parts to the panel as long as possible. This insulating material passes through the panel, so that in no place does the metal switch stud come in contact with the marble. This is a necessary precaution in cases where very high pressures are handled, because the marble cannot be depended on to give good enough insulation. The blades *A*, *B* are arranged as described in connection with Fig. 4, except that blade *A* has a hole in the end instead of a handle. The switch is pulled open by means of a hook in the end of a handle about 3 feet long, thus allowing the attendant to stand back some distance and avoid the danger of his being burned by the arc. To avoid arcing from one switch to the next, marble barriers *C* are mounted at right angles to the main part of the board. Each switch is thus placed in a cell by itself, and arcing across from one switch to its neighbor cannot take place.

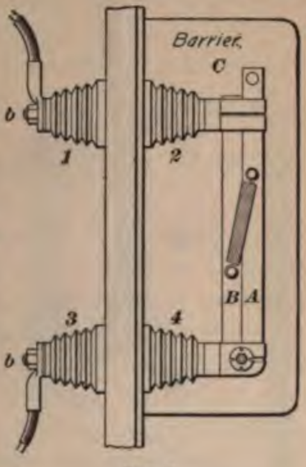


FIG. 6.

5. The Westinghouse Company make use of a high-tension switch in which the terminals are mounted at each end of a porcelain cylinder. A copper rod or plunger passes through these contacts or bushings and completes the circuit. When the plunger is withdrawn, the arc is formed in the confined space between the bushings. A small outlet is provided in the side of the tube, and when the arc is formed, the blast caused by the sudden expansion of the air in the confined space, together with the cooling action of the porcelain walls, extinguishes the arc. If the pressure to be handled is very high, a number of these cylinders are connected in series, thus producing a long break. Fig. 7 (*a*) and (*b*) shows a switch of the plunger type that is intended for a two-phase dynamo or circuit. This switch gives a double-pole double break in each phase. The cylinders *1*, *2*, *3*, etc. and plungers *1′*, *2′*, *3* are mounted on the back of the board and are operated by a lever *L* on the front. The

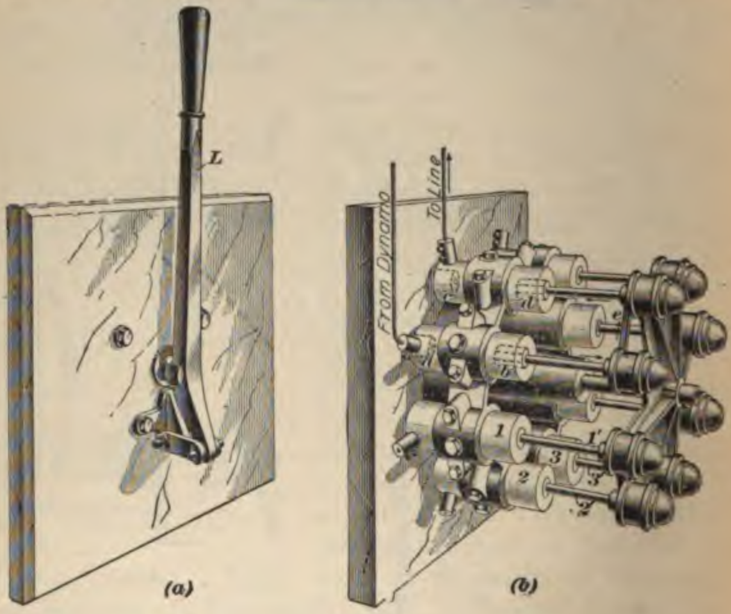


FIG. 7.

switch must accommodate 4 dynamo wires and 4 line wires, hence there are 8 cylinders, thus giving a double break in each line. The path of the current will be understood by referring to the arrows. In the figure the switch is shown thrown out, but when the plunger is in, bushings *a* and *b*, *c* and *d* are connected together, and the path of the current is *a–b–c–d–c* to line. When the plunger is withdrawn the arc is broken between *a* and *b*, *c* and *d*.

6. When large currents at high pressures are to be handled, the General Electric Company uses switches in which the arc is broken under oil. It has been found that a comparatively short break is sufficient under such circumstances, because as soon as the arc is formed the oil rushes into the gap and extinguishes it. Switches operating on this principle are in use in a number of the larger installations. Most of the larger sizes are operated by air pressure or a small electric motor, though in some cases they are arranged for hand control.

7. The variety of switches made is very large, and in selecting them for any special line of work the main points to look out for are, first, to see that the switch is capable of carrying the current without overheating or arcing when the circuit is broken; and, second, to see that it is substantially constructed. Switches on lighting boards are open and closed quite frequently, owing to changing over the circuits and dynamos. If these switches are not strongly built, they will be continually working loose and giving trouble, hence the importance of paying close attention to the mechanical construction.

8. Bus-Bars. — On high-tension, alternating-current switchboards, the bus-bars do not need to be very heavy, but on low-tension boards, where several hundred or, perhaps, thousand amperes are handled, they must have a large cross-section. They should have a cross-section of at least 1 square inch per thousand amperes carried and should be arranged so that the heat generated in them may be readily radiated. They should always be substantially mounted on the back of the switchboard and should be very carefully insulated. This last precaution is specially necessary in plants where the pressure between the bus-bars is high. The bars are usually of flat rectangular cross-section, and if an unusually large carrying capacity is needed, a number of these bars are built up together with air spaces between them to allow ventilation. Round bars are sometimes used, but they are not as common as the flat bars. For alternating-current bus-bars of large capacity, copper tubes are sometimes used, because, when an alternating current is sent through a heavy conductor, it is found that the current flows for the most part in the outside portion of the conductor. The method of building up bars out of thin strips, with air spaces between, is used also for alternating-current boards where a large volume of current is to be handled. The bus-bars are usually connected to the dynamo and feeder switches, either by means of copper strips, as shown in Fig. 8, or by means of cables provided with terminals, as shown in Fig. 9. All these connecting pieces should have a cross-section of not less than 1 square inch per 1,000 amperes.

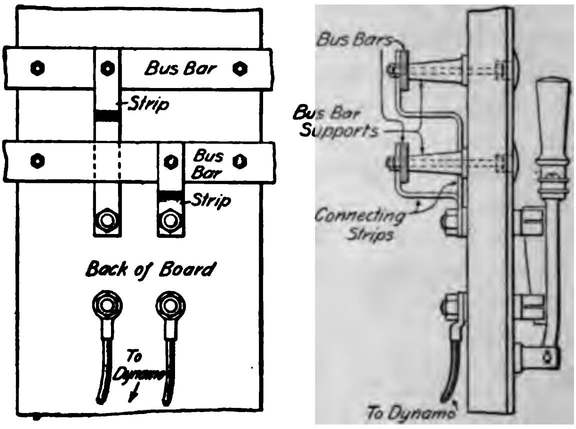


FIG. 8.

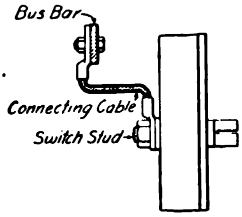


FIG. 9.

AMMETERS AND VOLTMETERS.

9. It is necessary to use ammeters in order that the current supplied by any dynamo or feeder may be seen at a glance. Voltmeters must be used in order that the pressure on the dynamo or feeders may be determined. It is usually the custom to equip each dynamo with an ammeter, or, in the case of multiphase machines, with one or more ammeters. In many cases, each feeder is also provided with an ammeter, so that the current supplied to any particular part of the system may be determined. Feeder ammeters are, however, not always considered essential, and, as a rule, one or two voltmeters are sufficient for most installations. It is unnecessary to go to the expense of installing a voltmeter for each machine or feeder, because a switch or series of plug connections can easily be provided, by means of which the voltmeter may be connected to any dynamo or circuit in order to obtain a reading. Ammeters and voltmeters are generally very similar in construction, the main difference being that the ammeter is of low resistance and is connected in series in the circuit; whereas, the voltmeter is of high resistance and is connected across the circuit. Some kinds of meters will operate with either direct or alternating current; others will work on direct current only. Most of the instruments in use are electromagnetic in principle.

10. Weston Ammeters and Voltmeters.—The Weston instruments are probably more widely used on switchboards than any others intended for direct current. Weston ammeters and voltmeters of the direct-current type should never be connected upon alternating-current circuits. A swinging coil *c*, Fig. 10, is mounted so as to swing between the pole pieces *N*, *S* of a permanent magnet. Current is led into the coil by means of the spiral springs *s*, *s'*, which also serve to counterbalance the movement of the coil. When a current flows through the coil, it reacts on the magnetic field, and causes it to swing around like the armature of an electric motor. It is evident that if an alternating current were sent through the instrument, the coil would tend to swing first in one direction and then in the other, so that no deflection would result. The switchboard, Fig. 56, shows the type of Weston instruments used for switchboard work. The voltmeter *V* and ammeter *M* are mounted in iron cases, and the dial is ruled on opal glass, which is illuminated from behind by means of incandescent lamps. The cheaper style, or "round type," without illuminated dials, is shown by the ammeters *a*, *a*. The voltmeters have a high-resistance coil mounted in the case and connected in series with

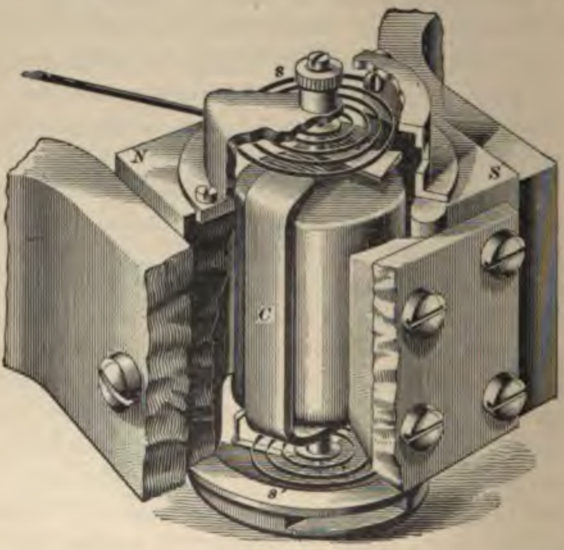


FIG. 10.

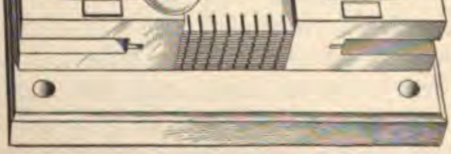


FIG. 11.

the swinging coil. In the case of the ammeter, it is not possible to send all the current through the coil, so only a small proportion of it is used; the remainder passes through the **ammeter shunt.** The ammeter shunt shown in Fig. 11 is a very low resistance, which is connected in series in the circuit the current in which is to be measured. For example, suppose the dynamo *A*, Fig. 12, supplies current to the bus-bars *B*, *C*, and we wish to connect an ammeter so as to measure the current supplied by the dynamo. The ammeter shunt *S* would be connected in series, as shown, and two small wires *1*, *2* taken from the terminals of the shunt to the ammeter *M*. The result of this arrangement is that only a small portion of the current passes through the instrument. But as the resistance of the shunt and ammeter is fixed with regard to each other, it follows that the current through the ammeter will always be a fixed proportion of that in the main circuit, and the scale may be marked so as to read the main current and not the current actually flowing through the meter. The use of a shunt is of great convenience, because it does away with the necessity of running heavy connections to the meter itself. The shunt may be placed at any convenient point, and it is an easy matter to run the light flexible connections from it. It may be well to state here that the small connecting cables running from the shunt to the instrument are sent out with the shunt. They are usually made long enough to reach any reasonable distance on the switchboard. They should on no account be altered in length; if they are too long, they should be coiled up out of the way; if too short, another shunt with long leads with its corresponding instrument should be obtained.

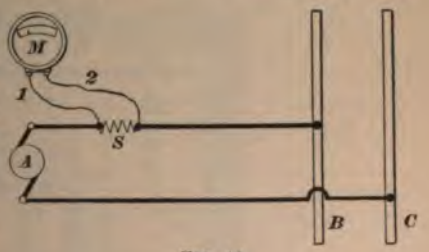


FIG. 12.

Fig. 11 shows the ordinary type of shunt used. It consists of the two terminals *a*, *a* connected together by the flat strips *b*, which are made of an alloy that has practically a constant resistance regardless of temperature changes; *c*, *c* are the small flexible cables that run to the ammeter.

The shunts and instruments are always numbered to correspond, and care should be taken to see that these numbers match before connecting up the instruments. Many other makes of instrument other than the Weston are used in connection with shunts.

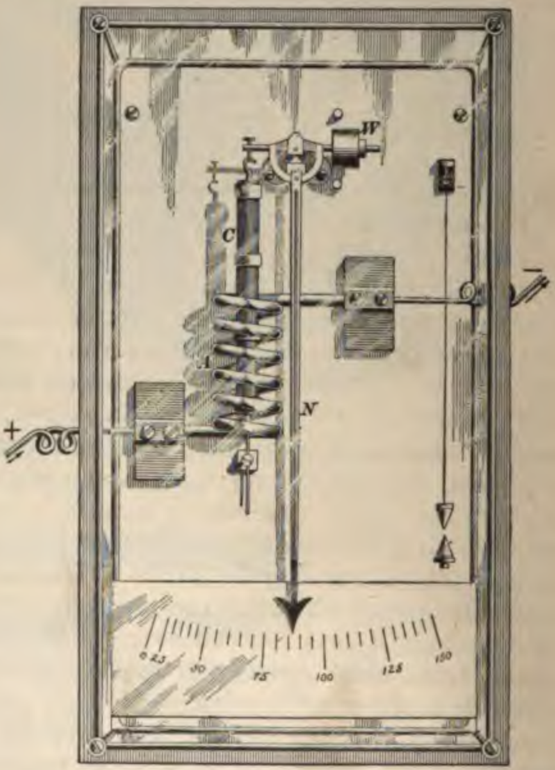


FIG. 13.

11. Alternating-Current Ammeters and Voltmeters. Most of the switchboard ammeters and voltmeters for alternating current consist of a coil arranged so that the magnetic field set up through it will act on a piece of iron, the movements of which actuate a pointer. Various modifications of this coil-and-plunger type are in common use. For example, in the earlier type of Westinghouse instruments, Fig. 13, a vertical coil *A* is arranged so as to draw an iron core *C* into it. This core is hung on one end of a balance arm to which the pointer *N* is attached, and a counterweight *W* is hung from the other end. In the later instruments, the current is sent through a coil, and the magnetic field produced deflects a small iron vane placed within it. Fig. 14 illustrates the principle of a type of instrument that has been largely used by the General Electric Company, both for alternating and direct current. It is known as the Thomson inclined-coil pattern. The coil *c*, through which the current flows, is mounted on an angle, as shown. A vertical shaft passes through the coil, and on it is mounted a small iron vane *v*. This vane is mounted at an angle to the shaft, and when the hand is at the zero position, the vane lies at an angle to the lines of force that, when a current flows, thread through the coil as shown by the arrows. As soon as a field is set up through the coil, the vane swings around so that it tends to lie parallel to the lines of force, as indicated by the dotted lines *v'*, thus giving a reading on the scale *S*. The movement of the needle *p* is controlled by means of the springs *a*, *a'*. The instruments shown on the alternating-current switchboard, Fig. 60, are of this type.

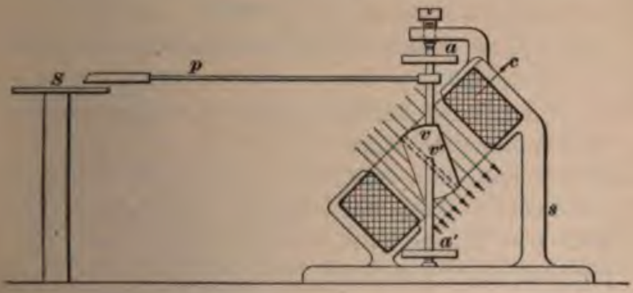


FIG. 14.

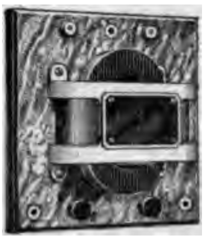


FIG. 15.

12. Potential Transformers.—It is not usual to connect voltmeters of the ordinary type directly across the line on alternating-current boards, because the pressure is so great that a voltmeter would have to have an exceedingly high resistance to permit its being so connected. Of course, if the pressure were low they could be connected in the ordinary way. In case the pressure is high, a small **potential transformer** is used to step down the voltage. Fig. 15 shows a transformer of this kind. It is generally mounted on the back of the switchboard; its primary coil is connected to the line and its secondary to the voltmeter, as shown in Fig. 16. It is bad practice to run switchboard lamps from the potential transformer, because, as a rule, the transformer does not have sufficient capacity for this purpose, and, besides, it is liable to interfere seriously with the accuracy of the voltmeter readings. The voltmeters are usually graduated to read the secondary voltage, as this is what is generally required. In some cases, however, they are graduated so as to read the primary voltage.

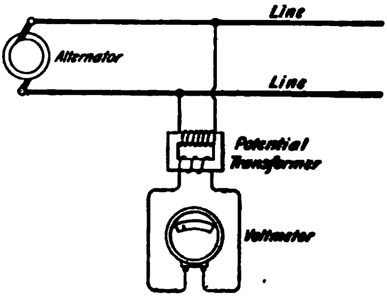


FIG. 16.

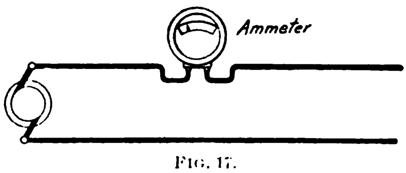


FIG. 17.

13. Current Transformers.—Alternating-current ammeters are in most cases connected directly in circuit. Shunts cannot, as a rule, be used with alternating-current ammeters, because, on account of the self-induction of the coil in the instrument, the current will not divide proportionally. Generally, the current to be handled on an alternating-current board is comparatively small, because the pressures used are high and there is no great difficulty in running the main wire directly through the instrument, as shown in Fig. 17. If, however, the current is large, or, what is often the case, if the generator pressure is so high that it is not desirable to have the main wires in contact with the instrument in any way, a **current transformer** is inserted in the circuit, as shown in Fig. 18. This is a small transformer, of which the primary coil *P* consists of a few turns of heavy conductor sufficiently large to carry the whole current. In some cases, where the current is very large, there may be only a fraction of a turn. The secondary *S* is of small wire and consists of a comparatively large number of turns. The secondary is connected to the ammeter, and as the current increases in the primary, it causes a proportional increase in the current through the ammeter. The ammeter may thus be calibrated so as to indicate the main current, though the main current does not actually pass through it, and it is at the same time entirely disconnected from the high-pressure dynamo leads.

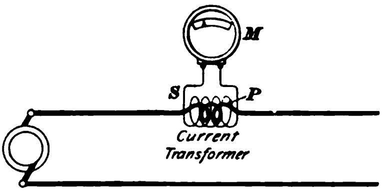


FIG. 18.

14. Electrostatic Voltmeters.—There is one kind of voltmeter that is sometimes used, especially for high-pressure alternating-current work, that differs considerably from the instruments so far described, both as to its construction and principle of operation. This is the **electrostatic voltmeter.** It depends for its action on the principle that two bodies carrying similar static charges repel each other and those carrying unlike charges attract each other. Fig. 19 shows the construction of the Stanley electrostatic voltmeter. *B*, *B* and *C*, *C* are fixed plates mounted on a hard-rubber base. These plates are covered with a hard-rubber covering *H* to prevent the charge from leaking off, also to

obviate any danger of short-circuiting between the vanes. *A* is a movable aluminum vane, to which is attached the pointer, the movement of which is counterbalanced by the spiral spring *S*. The fixed plates *B*, *B* and the movable vane *A* are connected together and form one pole of the instrument. The fixed plates *C*, *C* are connected together and form the other pole. When the voltmeter is connected

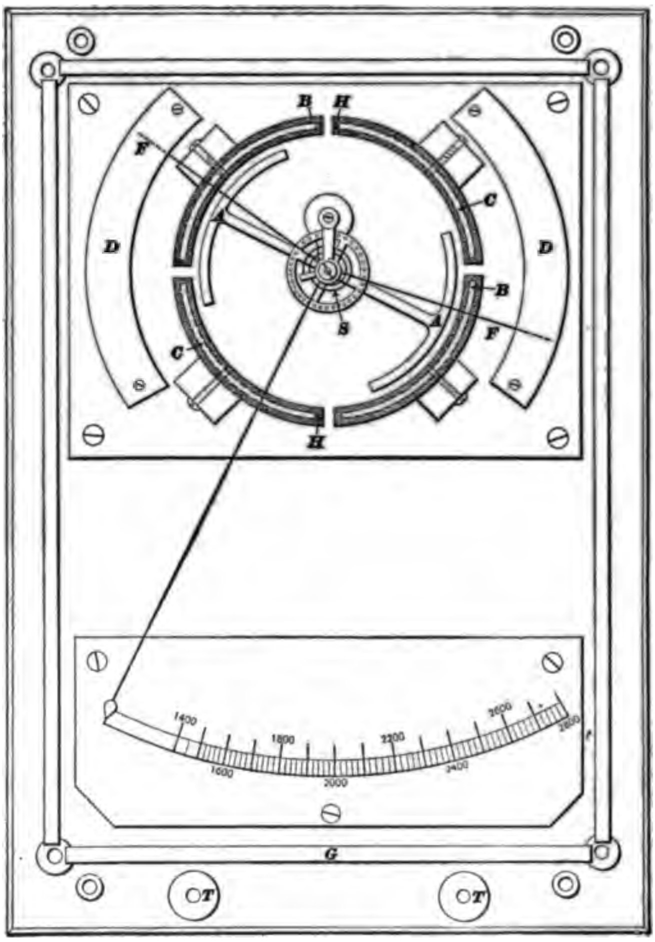


FIG. 10.

to the circuit, *B* and *A* being charged alike will repel each other, while at the same time *C* and *A* will attract each other, with the result that the vane is deflected an amount depending on the pressure of the circuit. Two plug receptacles *T*, *T* are provided on the instrument, in addition to the regular terminals, so that it may be compared at any time with a standard instrument. The movement of the needle is damped or steadied by the vanes *F* moving in the partially closed boxes *D*.

Other types of electrostatic instruments are made, but they all work on about the same principle. They do not, of course, require any current for their operation and can be connected across high-pressure lines without the intervention of a potential transformer.

15. Voltmeter Switches and Connections.—It has already been stated that it is customary to make one voltmeter answer for several dynamos or circuits by using a

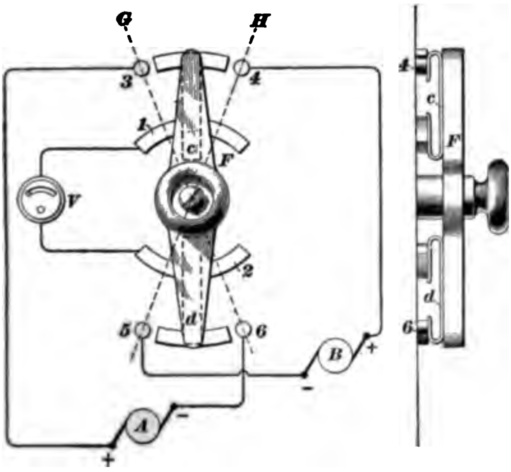


FIG. 20.

voltmeter switch or plug. Fig. 20 shows one of the simplest forms of switch used for this purpose. This is suitable for two dynamos, and its method of operation is obvious from the figure. The voltmeter is connected to terminals *1* and *2*, and the dynamos *A*, *B* to *3* and *6*, *4* and *5*. Connection is made to the terminals *3*, *4*, *5*, *6* by means of the spring contact pieces *c*, *d* that are attached to the insulating cross-arm *F* and rub on the arcs *1* and *2*. In position *G*, machine *A* is connected to the voltmeter, and in position *H*, machine *B* is connected. Sometimes voltmeters are connected by means of a flexible cable that is attached to a plug that may be inserted in receptacles connected to the different dynamos. The use of a cable is, however, somewhat objectionable, and in order that it may be avoided, the plugging arrangement shown in Fig. 21 has been largely adopted. A pair of wires *a*, *b* are connected to the voltmeter *V*, and taps are run from these to the plug receptacles *1*, *1'*. The different dynamos are connected to receptacles *2*, *2'*, and when a voltmeter reading from any generator is desired, a plug is inserted into the receptacle corresponding to that generator. This plug is arranged somewhat as shown in Fig. 22, and when it is inserted, it connects points *1* and *2*, *1'* and *2'* together, as indicated by the dotted lines, Fig. 21.

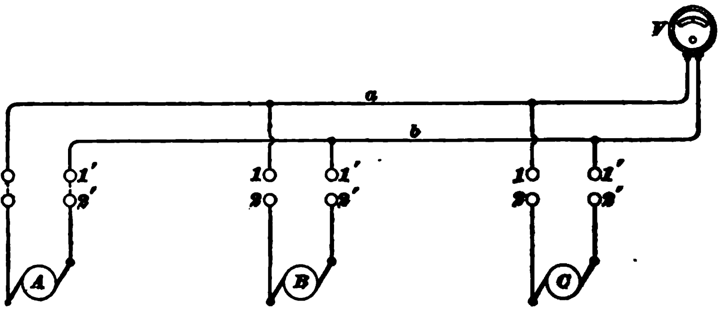


FIG. 21.

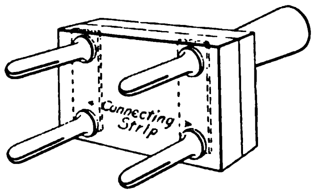


FIG. 22.

16. Pressure Wires.—In most cases, it is necessary to know the pressure that is being maintained at the center of distribution, where the light is supplied, rather than at the station; i. e., the voltmeter should give indications of the pressure delivered, and the pressure at the generator will be greater than this by the amount of the drop in the line. In order to indicate the pressure delivered, it has been customary in some cases to run *pressure wires* back to the station from the distributing center, as shown in Fig. 23. The wires *a*, *b* run back from the distributing center *c* and connect to the voltmeter *V*, either directly or through a potential transformer, as the case may be. The current required to operate the voltmeter is so small that there is practically no drop in the pressure wires. The pressure wires are of small cross-section, usually No. 8 or 10 when strung on poles. Insulated iron wire is often used for this purpose, as the current to be carried is very small.

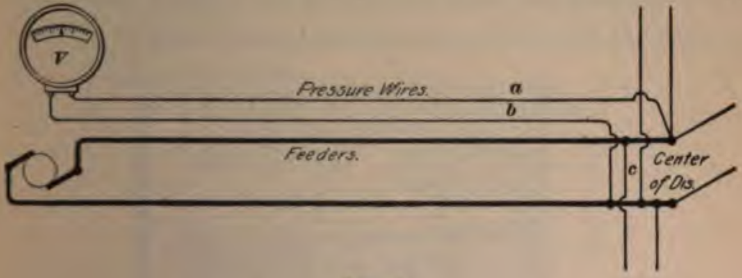


FIG. 23.

17. Compensating Voltmeter.—In order to avoid the necessity of running pressure wires back to the station, **compensating voltmeters** or **compensators** are sometimes used in connection with alternating plants. The compensator is a device used in connection with the voltmeter to decrease the voltmeter reading by an amount proportional to the drop in the line as the load increases. The attendant then increases the field excitation of the alternator and thus brings the pressure up to such an amount that the voltage at the distributing point is correct. Fig. 24 shows the general appearance of the Westinghouse compensator, and Fig. 25 shows how it is used in connection with the voltmeter. It consists of a small transformer, the primary of which is divided into a number of sections with leads brought out to terminal blocks *R*, *S*, *T*, etc., Fig. 24. The secondary is also divided into a number of sections with terminals brought to the contact points *1*, *2*, *3*, etc. The voltmeter is of the ordinary coil-and-plunger type with a small auxiliary coil *c*, Fig. 25, wound over the main coil *d*. The main coil is supplied with current from the potential transformer *T* in the ordinary way. The primary of the compensator is connected in series with the main circuit, as shown, and the secondary is connected to the small auxiliary coil. When the voltage at the distributing end of the line is at its correct value, the hand of the voltmeter is at its mid-position. When the load increases, the current through the primary of the compensator also increases; this, in turn, increases the current in the secondary, which is so connected to the auxiliary coil that the current in this coil opposes that in the main coil. The

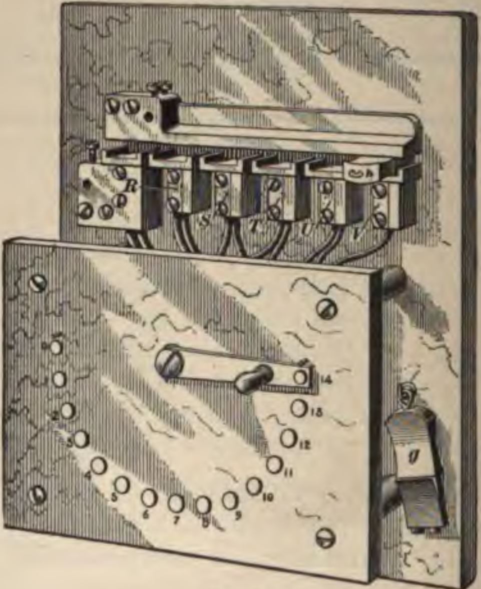


FIG. 24.

result is that the hand on the voltmeter goes back, and the pressure must be raised to bring it up to its proper value. By plugging in at different points on the primary and by setting at different points on the secondary, the compensator may be adjusted for operation on almost any of the circuits ordinarily met. After it is once set to suit the particular line on which it is to work, it requires no further attention. Tables are furnished with the instrument showing how to set it, and care must be taken in setting to insert the extra plug *g*, Fig. 24, before withdrawing the plug *h* already in use, otherwise the circuit will be opened.

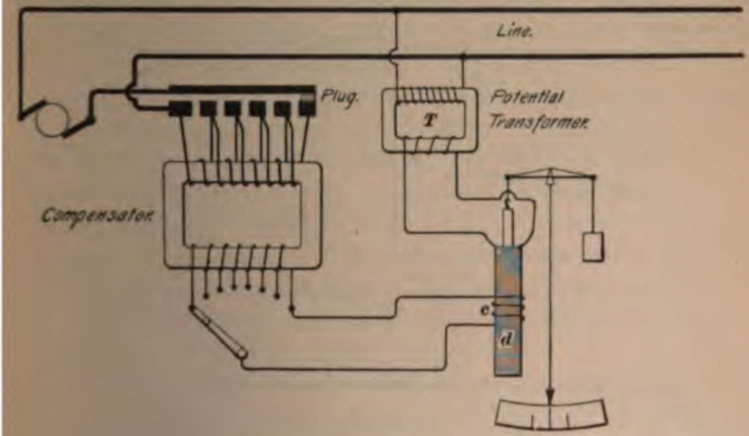


FIG. 25.

18. The Mershon Compensator.—The compensator described in the last article answers very well for lines that have little self-induction and that supply a lamp load. Where, however, the load is inductive, as, for example, a load of motors or a load of motors and lamps, the reactance of the line may have a very great influence on the drop in voltage, and if a compensator is to make the voltmeter give indications that are at all accurate, it must compensate not only for the ohmic drop in the line, but also for the drop due to the reactance. The Mershon compensator, brought out by the Westinghouse Company, is designed to accomplish this.

19. The principle on which this compensator operates is

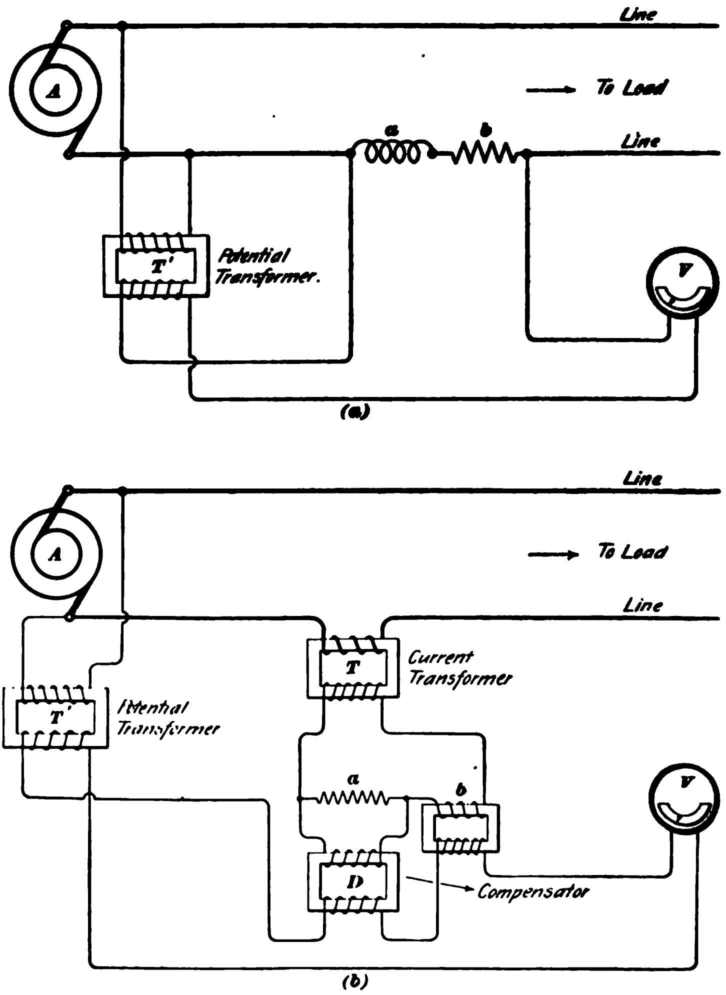


FIG. 28.

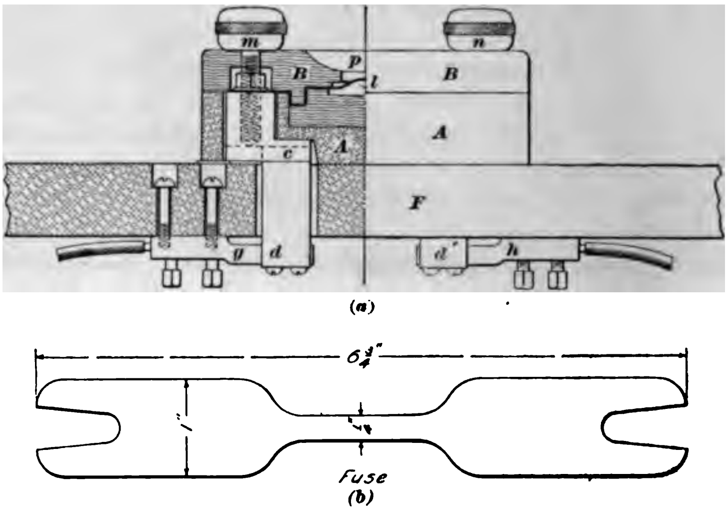
briefly as follows: The E. M. F. supplied at the end of the line is always equal to the resultant difference between the

E. M. F. generated and the E. M. F.'s necessary to overcome the resistance and reactance. If, then, three E. M. F.'s are set up at the station that are proportional to the above three E. M. F.'s and bear the same phase relation with regard to one another, and if these E. M. F.'s are combined in the same way as the line E. M. F.'s, it is evident that their resultant will make the voltmeter indicate the E. M. F. at the end of the line. For example, take the simple case shown in Fig. 26 (*a*). *A* is an alternator supplying current to the line. *T'* is an ordinary potential transformer, the secondary of which gives a voltage that is proportional to the generator voltage and in step with it. If the voltmeter *V* were connected directly to *T'*, it would evidently indicate the station voltage, but what is wanted is an indication of the voltage at the far end of the line, and in order to get this, the voltage of *T'* must be reduced by an amount equal to the sum of the drops caused by the reactance and resistance. In order to do this, an adjustable reactance *a* and an adjustable resistance *b* are inserted in the circuit. The drop through *b* will be proportional to and in step with the line resistance, and the voltage across *a* will be proportional to and in phase with the inductive drop. From the way in which the connections are made, it is easily seen that the voltage acting on *V* is a combination of the voltages of *T'*, *a*, and *b*. The drop across *a* and *b* will increase as the current in the line increases, hence the voltmeter reading will decrease (because the connections are made, so that the pressures across *a* and *b* cut down the E. M. F. applied to *V*). The voltmeter will, therefore, indicate the true pressure at the end of the line because both the ohmic and inductive drops are accounted for.

Fig. 26 (*a*) is intended to illustrate the principle only, the actual connections are more nearly as indicated in Fig. 26 (*b*). Here *A* is the alternator, as before, and *T'* the ordinary potential transformer. *T* is a small current transformer, the primary of which is connected in series with the line and the secondary to the compensator proper, which consists of three parts, *a*, *b*, and *D*. The E. M. F.

replaced, care should be taken to see that the switch connecting the fuse block with the dynamo is open. This fuse block is suitable for currents up to 150 amperes at 2,500 volts, and is the type of fuse shown on the switchboard in Fig. 60. For higher pressures fuse blocks are used in which the fuse is pulled wide apart as soon as it blows, thus breaking the arc.

The use of fuses on low-tension lighting switchboards is not as common as it once was, their place being taken by the automatic circuit-breaker. Fuses are, however, used largely for alternating-current boards and also for protecting individual circuits on low-tension, direct-current boards. They are not as convenient or reliable as circuit-breakers, because it takes time to replace them when they blow, and only too often they are replaced by a heavier fuse or even a copper wire, which is of scarcely any use as a protection. Again, fuses of the same size do not always blow at the same current, as much depends on the nature of the fuse-block terminals. If the clamps are not screwed up tightly,



(a)

(b)

FIG. 27.

local heating will result, and the fuse will blow with a smaller current than it should. Also, it has been found that a fuse of a given cross-section and material will carry a heavier current when the distance between the terminals is short than when it is long, on account of the conducting away of the heat by the terminals.

23. Circuit-Breakers.—The circuit-breaker is essentially an automatic switch that opens the circuit whenever the current becomes too large. The current is usually sent

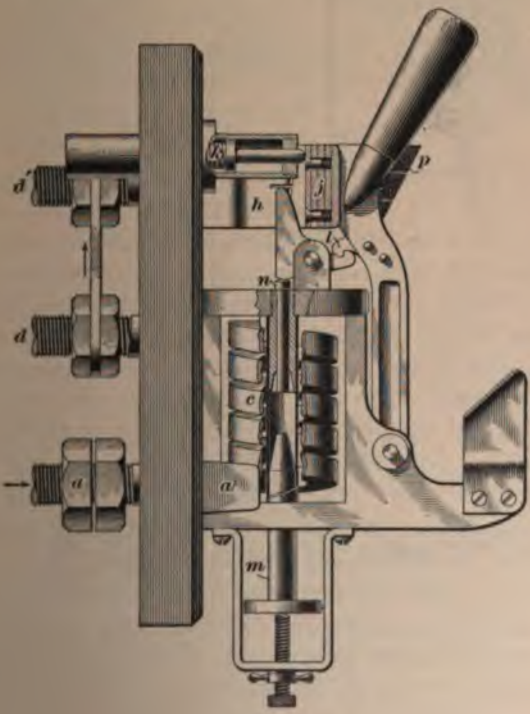


FIG. 28.

through an electromagnet or solenoid, which operates a trip and releases the switch when the current exceeds the amount for which the breaker is set. Fig. 28 shows a typical into 52 sections connected to the contact points *p* mounted on the slate front. By turning the hand wheel *H*, any number of sections may be cut in or out. Nearly all rheostats are made so that turning the handle to the right will cut in resistance and lower the voltage of the dynamo. This is the same direction that an ordinary globe valve is turned to shut off the steam or water. On most modern slate or marble boards, the rheostat is mounted on the back of the panel, and all that appears on the front is the hand-wheel necessary for operating it.

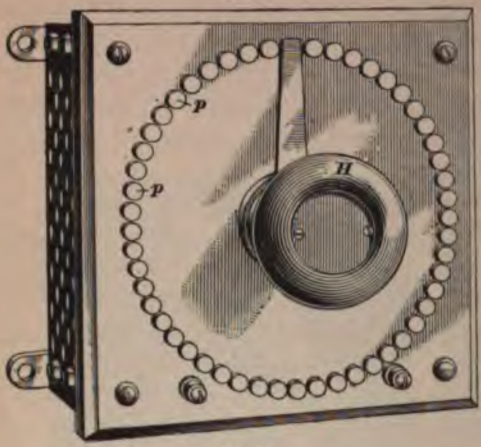


FIG. 33.

Fig. 34 shows a rheostat arranged in this way. The one shown is of the enamel type, in which the wire is made up into flat zigzag coils and embedded in enamel on the back of a ribbed iron plate. This holds the wire securely in place and at the same time allows it to impart the heat generated to the ribbed iron plate, which radiates it. The figure shows the operating wheel *H* that moves the arm *a* over the contacts *b*; *t*, *t'* are the terminals of the rheostat, and the whole is bolted to the panel by means of bolts *c*.

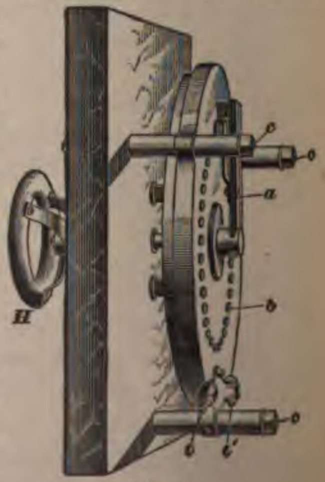


FIG. 34.

with a rheostat in series with their separately excited field, as well as with one in the shunt field of the exciter. In some cases, the latter alone is used, although it is desirable to have a rheostat in the alternator field, and it is almost absolutely necessary if the plant is arranged so that one exciter may supply the fields of several machines, as is frequently done in large plants. The method of connecting rheostats will be shown later, when the subject of switchboard connections is taken up.

26. The rheostat usually consists of a number of coils made up of iron, German-silver, or other wire having a high resistance. These coils may be mounted in a variety of ways. Sometimes they are wound in spiral form and mounted in a cast-iron box. In other cases, they are mounted on an iron plate and bedded in enamel. Whatever method is used, the mounting should be perfectly fireproof and at the same time allow the coils to radiate the heat readily. The resistance is divided into a large number of sections, so that the current in the shunt field may be varied by small amounts, thus giving a correspondingly fine adjustment of E. M. F. It may be mentioned, in passing, that the field rheostat used in connection with a compound-wound machine is not usually varied to any great extent after the machine has settled down to its normal operation. When the dynamo is first started up, its fields are cold, but after it has been running a while, they warm up and their resistance increases so that it is necessary to cut out some of the rheostat in order to keep up the voltage. However, after the fields have reached their normal temperature, the compound coils will generally take care of the voltage, and very little further adjustment of the field rheostat is necessary. Field rheostats are made in many different styles, and a great many different schemes have been adopted for making up and mounting the resistance.

Fig. 33 shows the appearance of a typical field rheostat mounted in an iron box and arranged for attachment to the front of the switchboard. The resistance is here divided

In order to indicate grounds, the voltmeter may be connected as shown in Fig. 35 (*a*); *a* and *b* are the mains connected to a two-point switch; *c*, the blade, is connected through the voltmeter *V* to the ground. If the line *a* should become grounded, as indicated by the dotted line, and the switch blade placed on point *1*, no deflection would result. If, however, the blade is moved to point *2*, current will pass from line *a* through the ground on the line to the voltmeter to point *2*, and thence to the line *b*, thus completing the circuit. When a deflection is obtained on point *2*, it shows that line *a* is grounded; and when obtained on point *1*, it shows that line *b* is grounded. If the ground is of high resistance, the deflection will be comparatively small; if of low resistance, the deflection will be large. Many direct-current voltmeters, for example, the Weston, require that the current shall flow in them always in the same direction, in order that they may give a deflection over the scale. In Fig. 35 (*a*), it is easily seen that the current will flow through the voltmeter in the opposite direction on point *2* from what it will on point *1*, hence the voltmeter must have its zero point in the center of the scale, so that it can read either way.

Most voltmeters have their zero point at the left-hand end of the scale, and it is often convenient to have a switch that will allow the ordinary voltmeter to be used either as a voltmeter or ground detector. Fig. 35 (*b*) shows an arrangement for doing this. The switch *S* is similar in construction to that shown in Fig. 20, but the connections are arranged so that when the switch is in the position *1–1'*, the voltmeter *V* is connected directly across the line and gives the voltage on the system. When the switch is in the position *3–3'*, the voltmeter indicates any grounds, such as *G''*, that may be present on line *b*. When *S* occupies the position *2–2'*, *V* indicates grounds on line *a*, as at *G'*. By tracing out the path of the current in each case, the student will see that the current always flows through the voltmeter in the same direction.

28. Another very common arrangement for detecting grounds is shown in Fig. 36. Here two lamps *c*, *d* are connected in series across the lines. The voltage at which these lamps are designed to run is equal to that of the dynamo, so that when the two are connected in series, they will burn dull red. At the point between the lamps, a connection is made to ground through a switch or a push button *f*. If contact is made at *f* and if there is no ground on either line, the brilliancy of either lamp will not be altered. Suppose, however, that there is a ground on *b*, as indicated at *G'*. Now when the key is pressed, hardly any current will flow through lamp *d*, because the current will flow through *c* and *f* to the ground and thence to line *b*. In other words, lamp *d* will be shunted by the ground and it will go out. On the other hand, the cutting out of the high resistance of lamp *d* in series with *c* results in *c* burning brighter. The lamp that is connected to the side of the circuit on which the ground exists goes out or becomes dimmer, while the lamp on the other side brightens up correspondingly. This lamp detector is simple, and while it serves as an indicator of grounds, it is hardly as satisfactory as the voltmeter detector, as it does not give as accurate indications as to the resistance of the fault.

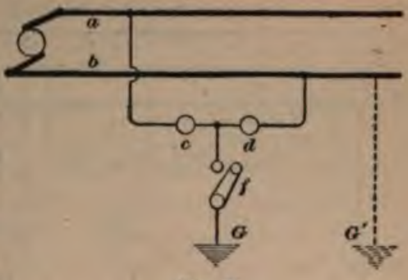


FIG. 36.

29. Fig. 37 shows a ground detector that is suitable for a three-wire low-tension system. Three lamps l_1, l_2, l_3 are connected in series across one side of the system, and a ground connection is made at *x* through key *K*. When all three lines are clear of grounds, the lamps will burn at a dull red, they will all be equal in brightness, and their color will not change when key *K* is pressed. Suppose that line *C* becomes grounded at *G'*; then, when *K* is pressed, lamp l_3

will be connected across lines *B*, *C*, and lamps l_1 and l_2 will be cut out; l_1 and l_2 will therefore go out, and l_3 will come up to full candlepower. If a ground occurs at *G'* on line *B*, lamp l_3 will go out and l_1, l_2 will brighten up, but will not come up to full candlepower because two of them will be in series between *B* and *C*. If there is a ground at *G'''* on line *A*, all the lamps will come up to full candlepower, because they will all get the full voltage, l_3 being across *A B* and l_1, l_2 in series across *A C*. It is thus seen that a ground on any one of the three lines affects the lamps differently, so that by noting their performance, the line on which there is a ground may be located.

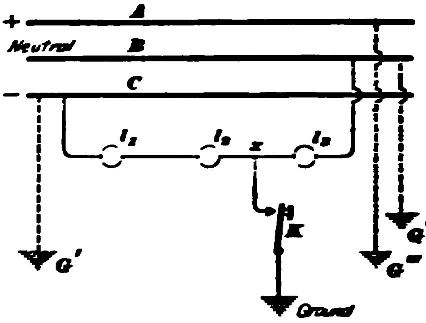


FIG. 37.

30. The ground detectors just described apply more particularly to low-tension direct-current installations, but similar arrangements may be used on alternating-current systems by using potential transformers. Fig. 38 shows the method used by the Westinghouse Company on some of their alternating-current switchboards. The regular voltmeter *V*, with which the switchboard is equipped, is here used also as a ground detector. *P* is a plug switch by means of which

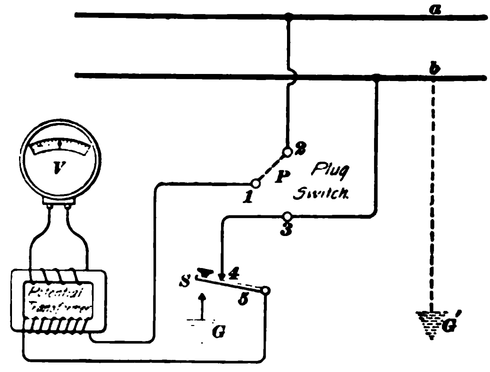


FIG. 38.

points *1* and *2* or *1* and *3* may be connected together. Under ordinary conditions, the plug is in *1* and *2*, thus connecting the primary of the potential transformer across the line, and *V* serves as an ordinary voltmeter. *S* is a key, or push button, that, when pressed, connects one side of the line to ground through the transformer primary. If there happens to be a ground on the side *b*, as shown at *G′*, the voltmeter will give a reading, and the attendant can judge by the size of the deflection as to whether the ground is a serious one or not. The path of the current is *b*–*G′*–*G*–*5*–to primary–*1*–*2*–*a*. By placing the plug in points *1* and *3*, side *a* may be tested. When the key *S* is not pressed, the lever *5* is against contact *4*, so that *V* is connected as an ordinary voltmeter.

31. A ground detector that is suitable for high-tension alternating-current systems is shown in Fig. 39. This is one of the earlier types used by the Westinghouse Company, and is similar in principle to the lamp detector shown in Fig. 36. The only difference is that the lamps are operated by means of transformers *T*, *T′*. These transformers have their primaries connected in series across the high-tension lines and the middle point *x* can be connected to ground through the key *K*. The secondaries are connected directly to the lamps *l*, *l′*. If line *b* is grounded and *K* pressed, the primary of *T* will be cut out and lamp *l* will go out. Lamp *l′* will brighten up. When there are no grounds on the line,

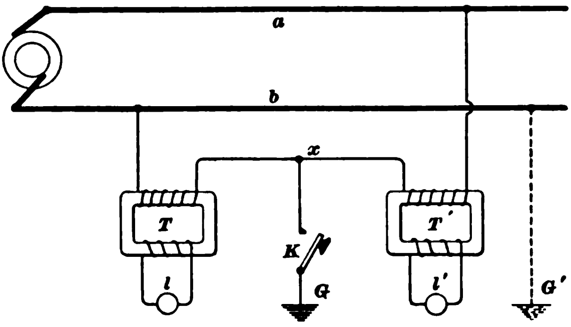


FIG. 39.

both lamps will burn dim and at equal brightness whether *K* is pressed or not.

32. Fig. 40 shows a form of alternating-current ground detector of which there are a considerable number in use. It was formerly used by the Thomson-Houston and General Electric Companies, but it has been replaced by the electrostatic ground detector in later installations. The principle of the electrostatic ground detector will be described later.

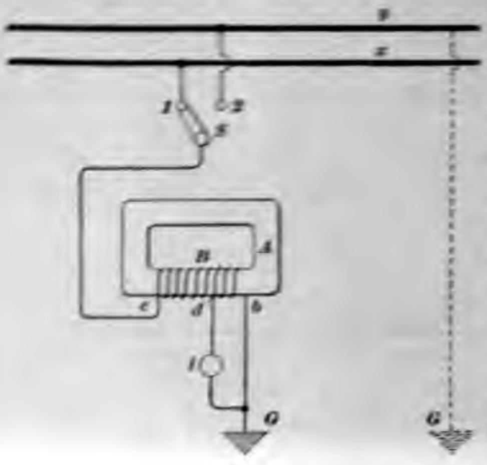


Fig. 40.

In Fig. 40, *A* represents a laminated iron core similar to a regular transformer core. On it is wound the coil *B*. One end of the coil *c* is arranged so that it may be connected to either side of the circuit through switch *S*, and the other end *b* is connected to the ground. A tap is brought from a point *d* and is connected to the lamp *l*, and the other terminal of *l* is connected to the ground. Suppose there is no ground on either line wire. Then if the switch is put on either points *1* or *2* the lamp will remain dark, because no current will flow through coil *B* to the ground. If there is a ground on the line *y* and the switch is placed on *1*, then current will flow from *y* to the ground, through *B*, and back to *x* by way of the switch and point *1*. This current will magnetize the core and set up a counter E. M. F. in coil *B*. The E. M. F. set up in the portion of the coil *d b* will cause the lamp to glow and thus indicate the ground. If the lamp glows when the switch is placed on point *2*, it indicates that there is a ground on line *x*.

In some forms of this ground dectector the switch is replaced by an insulated handle with a terminal on the end. This terminal is connected, by means of a flexible cable, to one terminal of coil B, and when tests are being made, the terminal is simply brought into contact with the various lines. This simplifies matters considerably where there are several circuits to be tested and avoids having a two-point switch for each pair of lines. Fig. 41 shows this type of ground detector provided with a plug p, by means of which it may be connected to any of the lines.

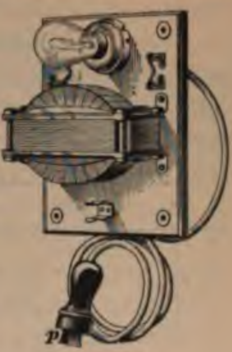


FIG. 41.

33. Electrostatic Ground Detector.—Ground detectors operating on the electrostatic principle are used to quite a large extent. They have the advantage that they require no current for their operation and may be left connected to the circuit all the time, thus indicating a ground as soon as it occurs. They also give an indication without it being necessary to make an actual connection between the line and ground, as is the case with all the detectors previously described. Fig. 42 illustrates the principle of the later style of Stanley electrostatic ground detector, which is specially adapted to high-pressure alternating-current lines because the instrument is not in actual connection with either of the lines. The instrument itself is enclosed in a hard-rubber casing and the parts are very similar to those of the voltmeter shown in Fig. 19. The fixed vanes 1 and 4, 2 and 3 are connected together in pairs, as shown. The movable vane V is connected to the ground and is held in the central position shown in the figure by means of small spiral springs S. The pairs of fixed plates are not connected direct to the lines, but are attached to plates a, a' of two small condensers. These condensers consist simply of two brass plates a, b that are mounted in hard rubber at some distance from each other. Plates b, b' are connected to the lines. When no grounds are present, *1* and *4*, *2* and *3* become oppositely charged by reason of charges induced on plates a, a' by plates b, b'. The forces acting on the vane V are, therefore, equal and opposite. Now suppose that line B becomes grounded at G''. This is equivalent to connecting vane V to line B; V takes up a charge similar to *2* and *3*, hence it is repelled by *2* and *3* and is attracted by *1* and *4*, thus giving a deflection. If A becomes grounded, a deflection in the opposite direction is obtained. Instruments of this kind can, of course, only be used in places where the pressure is fairly high, as the electrostatic forces produced by charges due to low pressures would not be large enough to operate an instrument unless it were made much too delicate to be of practical use in a light or power station. In most electrostatic detectors, the lines are connected directly to the fixed sectors *1*, *2*, *3*, *4* and the condensers C, C' are omitted.

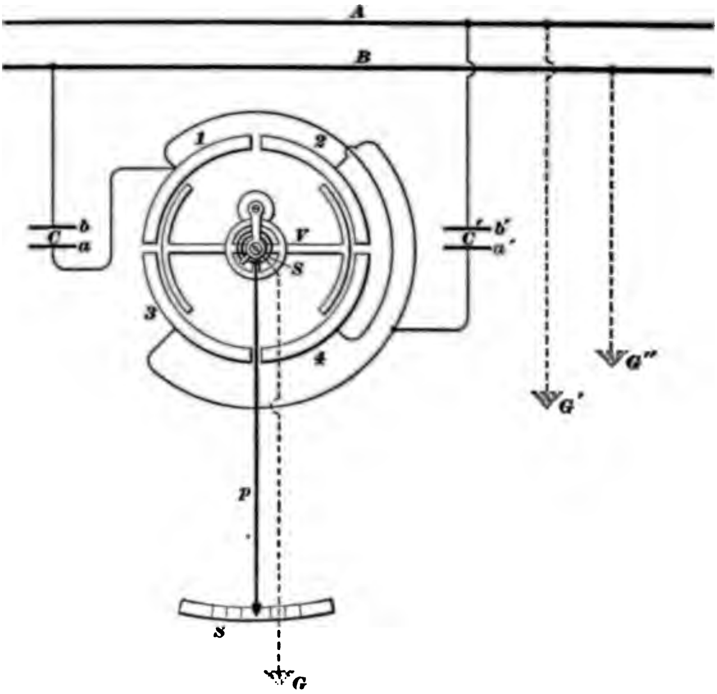


FIG. 42.

LIGHTNING ARRESTERS.

ARRESTERS FOR DIRECT CURRENT.

34. The general principles relating to lightning arresters have already been discussed, and we will here confine our attention to a description of some of the more common types that are used in connection with electric-lighting work. The arrester used for any given lighting system must be selected with due reference to the voltage and kind of current used. Arresters that would work well on alternating-current lines might be total failures when used with direct current, owing to their inability to put out the arc following the discharge. On the other hand, some arresters will work equally well either on direct or alternating current.

35. The Garton Arrester.—Fig. 43 illustrates the Garton arrester. The discharge points are of carbon, shown at *h* and *j*. These points are about $\frac{1}{32}$ inch apart, and the lower one is connected to ground; *f* is a coil of wire wound on the tube *g*, which is closed at the top; *e* is a small core of iron attached to the rod *d*, which in turn connects, by means of a small flexible cable, to one end of the resistance *b*. The other end of the coil connects to the other end of the resistance, to which the line also connects. The resistance *b* is made up of a stick of graphite and, having practically no inductance, it offers little or no opposition to the discharge. The discharge comes in over the line *a*, passes through *b* to the rod *d*, thence to the carbon point *h*, and jumps the air gap to the ground. The discharge is followed by current from the dynamo and, since the coil is in shunt with the resistance,

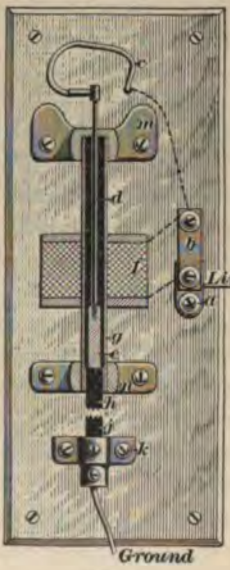


FIG. 43.

part of this current will flow through the coil, thus drawing up the core *c* and breaking the arc between *e* and *h*. The fact that the arc also takes place in the enclosed tube tends to put it out. As soon as the discharge has passed, the core drops back and the arrester is ready for the next discharge. This arrester is very simple and is not liable to get out of order. The spark gap should be examined now and then to see that it has not become enlarged or blocked up in any way. If the gap becomes too long, the lower carbon may be moved up a little. Sometimes arresters are connected as shown in Fig. 44, as this arrangement gives especially good protection. Here three kicking coils are connected in series and a lightning arrester is connected in ahead of each coil. The Garton arrester may be used on either direct-current or alternating-current circuits.

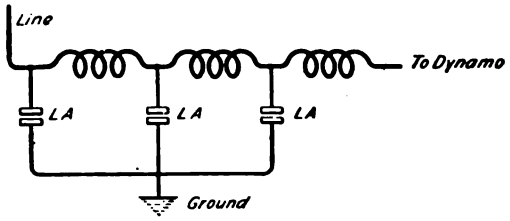


FIG. 44.

36. Westinghouse Arrester.—Fig. 45 shows the form of the Westinghouse arrester that is used on direct-current circuits. This arrester has no movable parts, and the arc is extinguished by smothering it in a confined space. Two terminals *b*, *b* are mounted on a lignum-vitæ block and are separated by a space somewhat less than ½ inch. This space is crossed by a number of charred grooves, so that although the resistance in ohms between the terminals is very high, yet the lightning will readily leap across the space. The block *A* is covered by a second

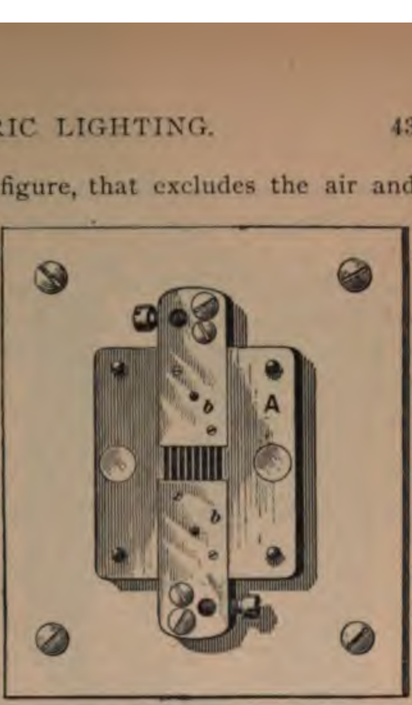


FIG. 45.

block, not shown in the figure, that excludes the air and confines the arc to the small space between the terminals. When the arc tends to follow the discharge, the small space is soon filled with the vapor of the metallic electrodes that will not support combustion, and the arc is put out. The connections of the arrester are very simple, one side being connected to the line and the other to ground. It should be noted that this arrester is intended for use on direct-current circuits only, and the pressure should not exceed 600 or 700 volts.

37. Magnetic Blow-Out Arresters.—Fig. 46 shows a lightning arrester that has been used extensively by the General Electric Company for low-pressure direct-current circuits. It is of the magnetic blow-out type, i. e., the arc that follows the discharge is extinguished by forcing it across a magnetic field until it is stretched out to such a length that it can no longer be maintained. The construction of the arrester will be understood by referring to Fig. 46. *A*, *A* are two coils of wire wound on the cores *B*, so that when current flows through them, poles

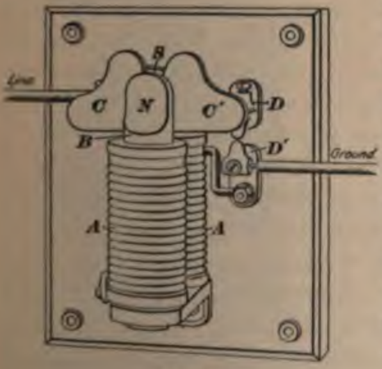


FIG. 46.

38. One of the objections to the arrester just described s that the discharge must jump a comparatively long air ap before reaching the round. In a later type f magnetic blow-out arester, the length of gap s much shorter. Fig. 48 hows the external appearnce of this arrester, and ig. 49 (*a*) and (*b*) shows he arrangement of the arts. Fig. 50 shows how he arrester is connected. ll the parts are mounted n porcelain. Fig. 49 (*b*) hows the porcelain box hat holds the blow-out oil *c* with its polar projecions *h*, *h*, also the graphte resistance *r*. The electrodes are mounted in the cover, ig. 49 (*a*), in connection with the clips *k*′, *k*′. When the

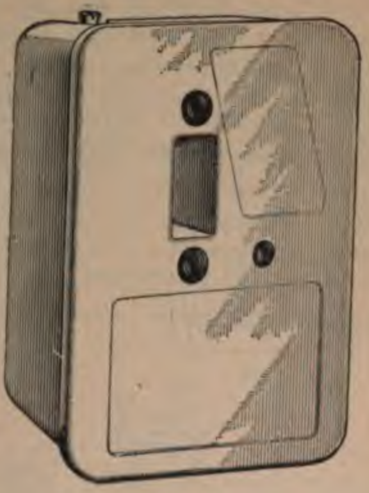
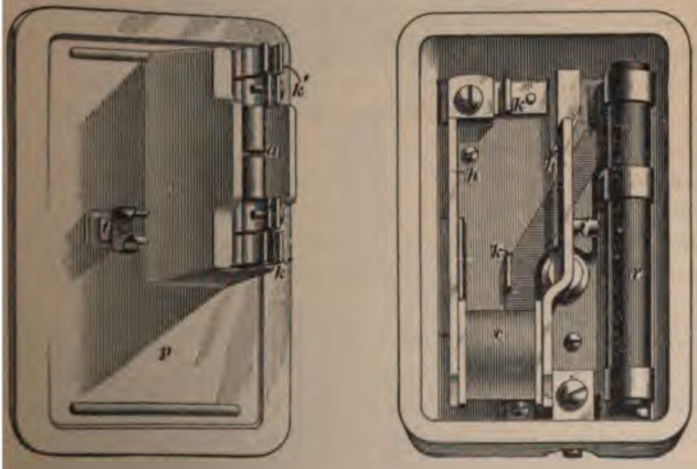


FIG. 48.



(*a*) (*b*)

FIG. 49.

the apparatus to be protected instead of passing through the gap. The length of the air gap may be adjusted by loosening the clamps and moving the electrodes nearer together.

ARRESTERS FOR ALTERNATING CURRENT.

39. Westinghouse Arrester for Alternating Current.—Fig. 51 shows a type of arrester that has been largely used by the Westinghouse Company on alternating-current circuits. It is known as the *Wurts non-arcing arrester*, and consists of a number of milled cylinders *a*, *a* mounted as shown and separated from each other by small air gaps. The end cylinders are connected to the lines and the middle cylinder to the ground. With this arrangement, a single arrester does for both sides of the line; where, however, the line pressure is high, a separate arrester is used for each side; and for very high pressures, such as are used on long-distance lines, a number of arresters are connected in series. When a discharge comes in over the line, it jumps

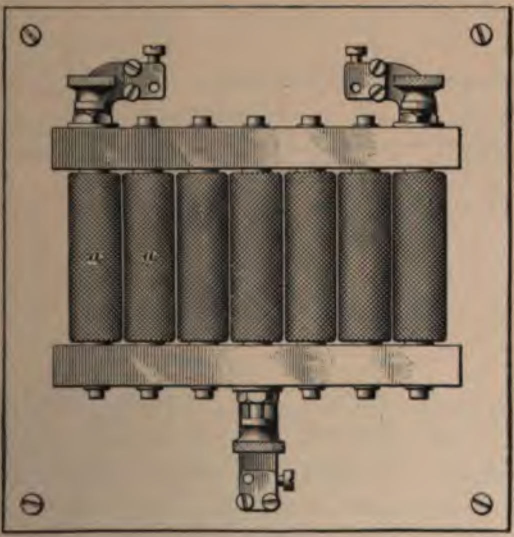


FIG. 51.

the gaps between the cylinders and passes to the ground. It is claimed that the arc does not hold over, because the gases formed by the volatilization of the metal will not support an arc. The cylinders are made of what is known as non-arcing metal. Others claim that the suppression of the arc is due to the cooling effect of the cylinders and the alternating nature of the current. The arc will be destructive if these arresters are used on direct-current circuits, but it will not be maintained on alternating-current circuits. The arresters should be examined from time to time and the cylinders rotated slightly so that they will present fresh surfaces to each other. Fig. 52 shows the method of connecting these arresters on 1,000-volt and 2,000 volt circuits.

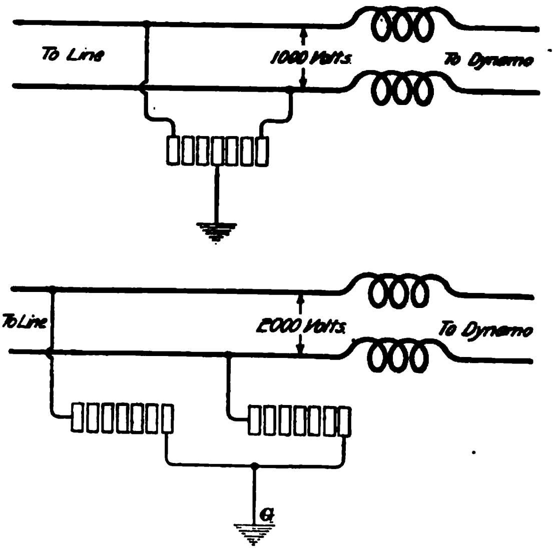


FIG. 52.

40. General Electric Arrester for Alternating Current. Fig. 53 shows an arrester used by the General Electric Company for alternating-current circuits. It is somewhat similar to the Wurts arrester just described,

;8m'294-

movable core arranged so that the magnetic flux passing through the secondary can be made to vary. Both these methods afford a means of obtaining regulation by more gradual steps than can be obtained with the Stillwell regulator. Potential regulators are usually placed at some point convenient to the switchboard, and in some cases the operating handles are mounted on the board itself and are geared, by chains and sprocket wheels, to the regulator.

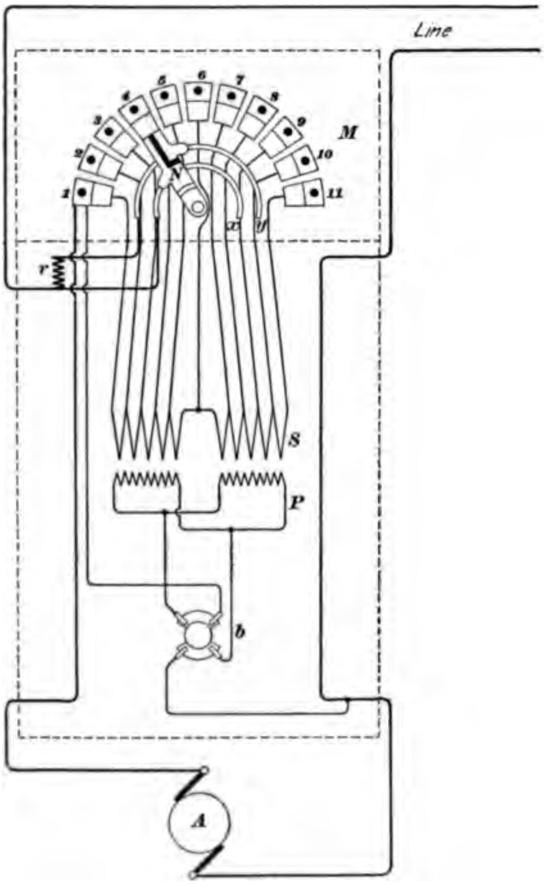


FIG. 66.

USE OF STORAGE BATTERIES IN LIGHTING PLANTS.

56. Within the last 8 or 10 years, the use of storage batteries in connection with lighting plants has steadily increased, for the advantages to be gained from its use are so great that many of the largest stations in the country are now equipped with them. The load on all lighting plants is a variable one. During the day the load may be very light, while for a few hours in the evening it may run up to a large amount. As this period of maximum load is generally of not more than 2 or 3 hours' duration, it is evident that if no means of storing electrical energy were provided, the plant would have to be equipped so as to handle this maximum-current supply. The result would be that the larger portion of the machinery in the plant would be idle for the greater part of the day, and, therefore, would represent so much investment that would not be earning anything.

57. The storage battery, as an auxiliary in a lighting station, may be used in a number of different ways:

1. It may be used to carry the "peak" of the load; i. e., it may be used to help out the dynamos during the interval when the load is heavy, for it can be charged during the daytime, when the demand on the dynamos is light.

2. It may be used to carry the whole load of the station during intervals of light load, thus allowing the generating plant to be shut down for repair and inspection.

3. Batteries may be installed in substations in districts where a large amount of light is used. These batteries may be charged, during the daytime, from the central station, when the load on the main feeders is light, and thus, when the heavy load comes on in the evening, they are able to relieve the main feeders by taking up a part of the lighting service. The use of storage-battery substations, therefore, allows many more lamps to be supplied without the necessity of laying more feeders.

58. The above are the main uses to which a battery may be put, but there are many other incidental advantages. For example, the effect of a battery connected across the system is always to keep the voltage steady. By preventing fluctuations in voltage, a more satisfactory service to the consumer is secured and lamps of high efficiency may be used. Again, the electrical energy stored in a battery is instantly available. Throwing a switch or two will put it into service, whereas it always takes more or less time to get a dynamo and engine started, especially if the units are very large. This is an important consideration, especially in large plants, because it provides against an interruption of the service in case of a breakdown. Moreover, in large city stations, the load often rises very rapidly; it may increase several thousand amperes in a few minutes, due to a sudden turning on of lights because of a storm coming up, and it takes time to start the large generating units, even if they are kept turning over slowly so as to be in readiness.

59. Battery Taking "Peak" of Load.—Fig. 67 shows the load curve of a large city station and illustrates how a battery may be used to relieve the generating machinery of the peak of the load. Shortly after 4 P. M. the load begins to rise rapidly and the battery is thrown into service, as indicated by the double-shaded area. The dynamos do not have to deliver more than 13,000 amperes, although the current used on the system rises to about 20,500 amperes. If the battery were not used, it is evident that sufficient machinery would have to be installed to handle 20,500 amperes. The single-shaded areas represent the intervals when the battery is charging. By using a battery in this way, a station can, in very many cases, provide for an increased output without installing any additional dynamos, engines, or boilers, and at the same time it can work the existing machinery to the best advantage at or near its full capacity. Not only this, but the battery largely avoids the danger of overloads on the machinery, thus reducing the danger of breakdowns.

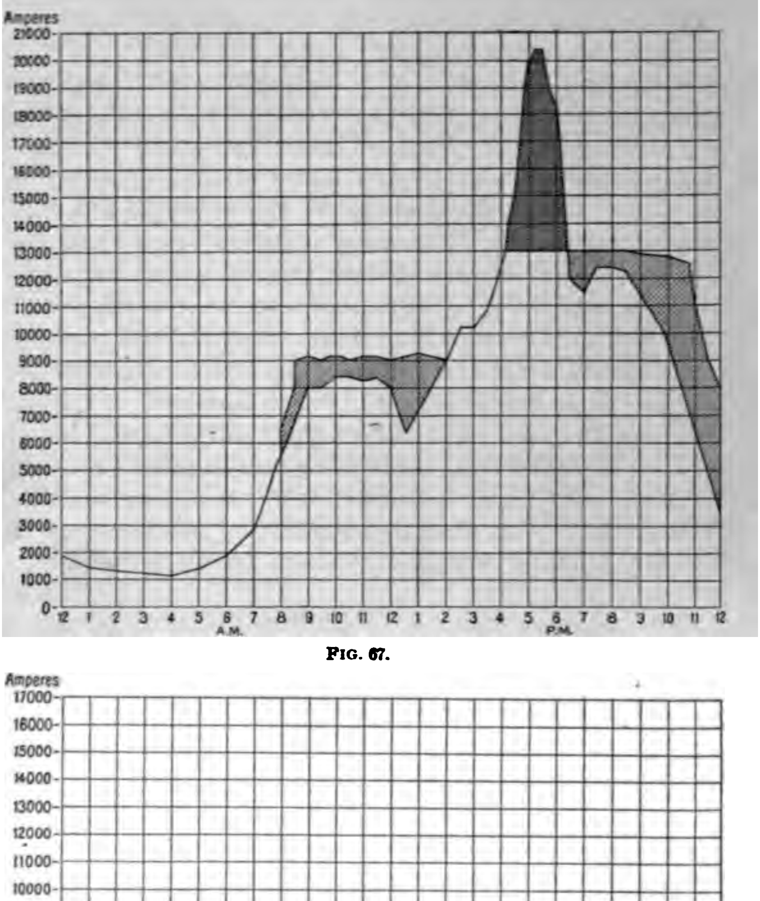

Amperes
21000
20000
19000
18000
17000
16000
15000
14000
13000
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
12 1 2 3 4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
A.M.
P.M.

FIG. 67.

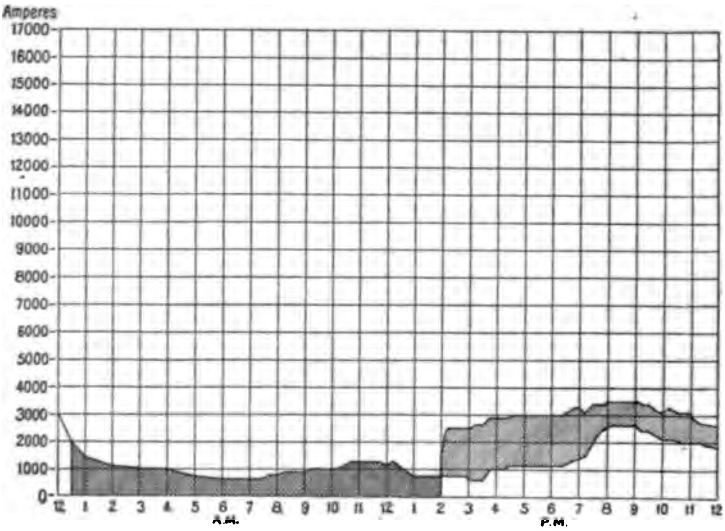

Amperes
17000
16000
15000
14000
13000
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
12 1 2 3 4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
A.M.
P.M.

FIG. 68.

60. Battery Carrying Whole Load on Station.—The curve, Fig. 68, shows the load curve for the same station as that shown in Fig. 67. This curve represents the load on a Sunday, and the load is very light compared with that shown in Fig. 67, because this station supplies a business district. It is seen that the generating plant is shut down altogether from 12.30 A. M. to 2 P. M., thus giving an opportunity for inspection or repair and allowing the station to be run with a small force of men. When the generators are started up at 2 P. M., the batteries are charged, as shown by the single-shaded area, thus allowing the generators in use to be run at more nearly their capacity, instead of on a light load only.

61. Battery Supplying Current From Substations. The use of storage batteries in this connection will be understood by referring to Fig. 69, where *A* represents the central station and *C* one of the substations. The three-wire system is here shown, as this is the one most largely used in distribution of this kind. The network of lamps fed from the substation *C* is represented by *D*. Now the load of lamps represented by *D* may be much in excess of what

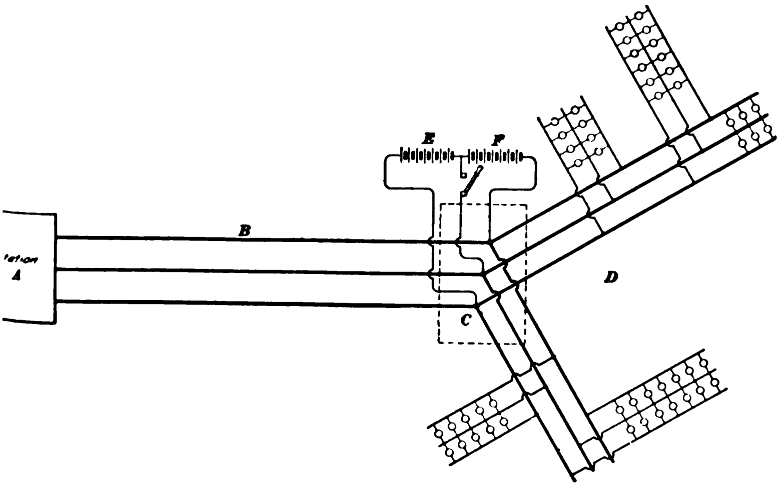


FIG. 69.

e supplied by the feeders *B* without causing a pro- drop. If, however, a battery *E F* is installed at *C* side of the system, it may be charged from the tral station during the daytime and thus relieve the eders at night, when the heavy load comes on. In other words, by using the battery, the feeders are worked at a more uniform rate throughout the day, instead of being ightly loaded the greater part of the time and heavily taxed when the peak of the load comes on. The use of the battery in substations not only equalizes the load on the dynamos, but also allow nount of service to be obtained from large cities, the use of storage-battery auxili has become almost a necessity on account reasing business. They avoid the expense of a ders and allow the addition of a considerable necessitating the installation of additional ma main station. Usually, the battery is connected outside lines, though a switch should be provided, wn, so that the middle point of the battery may be ected to the neutral, if desired. A battery used at the end of a set of feeders regulates automatically and requires no boosting arrangement. When the load is light, the pressure at the center of distribution is high and the battery is charged. When the load is heavy, the pressure at the center of distribution falls off and the battery discharges.

BATTERY EQUIPMENT FOR LIGHTING PLANTS.

62. Capacity Required.—The capacity of the battery that should be installed in any given case must be determined wholly by local conditions, and depends very largely on the nature of the load that the station carries. It also depends on the way in which the battery is to be used. The only intelligent way to arrive at the capacity required is to lay out a number of load curves for the station in question, similar to that shown in Fig. 67. By doing this, the number of ampere-hours that the battery should be capable of supplying can be approximated. In many cases, when installing plants of this kind, larger battery jars or tanks than those actually needed at the time are put in. The load is almost always sure to grow and the battery capacity may then be increased by simply adding a few more plates to each cell.

63. Type of Cell Used.—Storage cells designed for use in central stations must generally be of large size. For medium-sized cells, glass jars are used; but for the large types, the plates are mounted in strongly built wooden tanks lined with sheet lead and supported on glass or porcelain insulators. The chloride cell has been most largely used for this work in America. The plates used in these large cells are the same in construction as those described for the smaller ones. Fig. 70 gives a good idea as to the appearance and arrangement of some of the largest cells in use. Each cell here contains 87 plates 15½ in. × 32 in. The lugs *l*, *l* on the plates are burned on to the channel-shaped pieces *c*, which form the connections between the cells; *d* is the lead lining and *e*, *e* are glass rods for separating the plates; *m*, *n* are the heavy copper conductors leading from the battery. The space occupied by a battery for a given output will depend on the way in which the cells are arranged, i. e., whether in one or two tiers. Generally, however, 1,000 kilowatt-hours can be stored per 100 square yards of space. The number of cells required in an installation will depend on the voltage to be supplied. In large central stations operating on the three-wire 110–220-volt system, about 80 cells are used on each side of the circuit, though the exact number of cells depends considerably on the range of voltage required to meet special conditions.

64. Regulation of Batteries.—In order to fully charge the cells, it is necessary to have a voltage somewhat higher than that on which the system is ordinarily run. Of course, this might be obtained by running the generators at a high voltage, but in most cases this is not practicable, because the

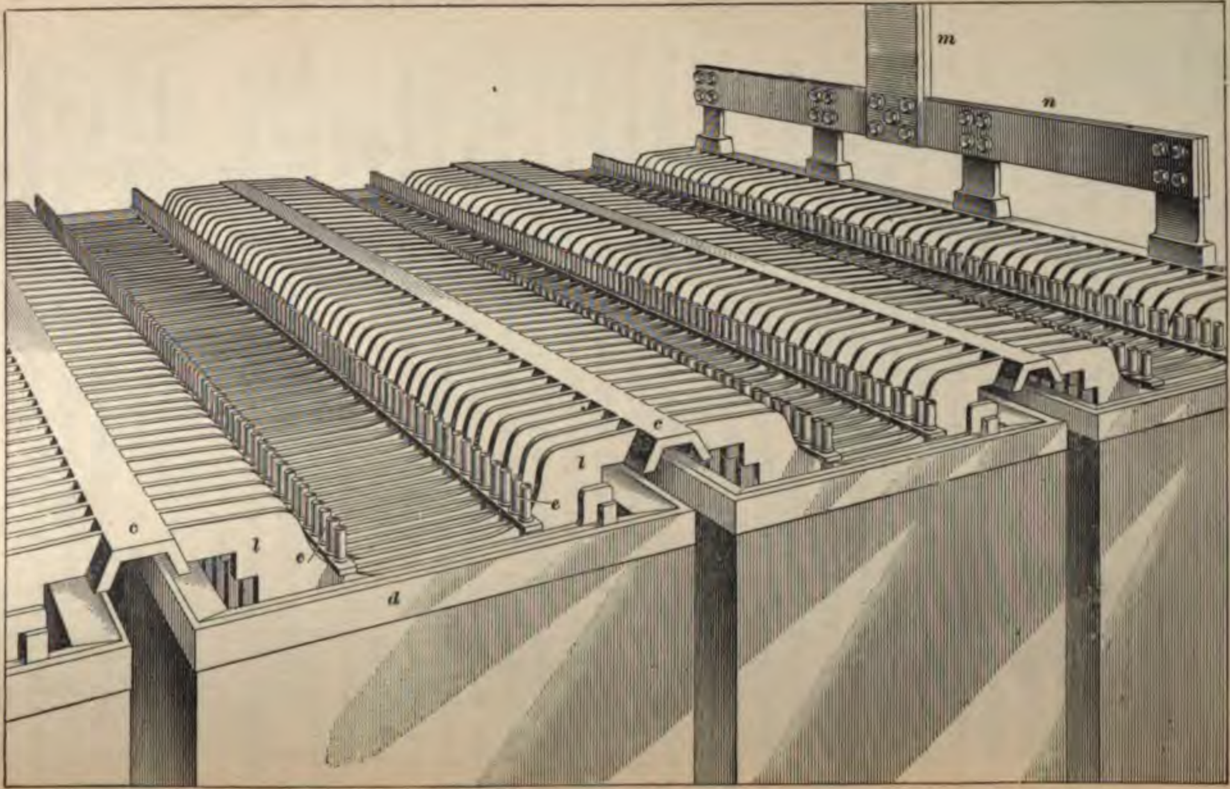


FIG. 70

machines are generally used to supply current for lighting at the same time that they are charging the cells. In order, then, to raise the voltage on the battery, a "booster" is used when charging is going on. In lighting work, the booster is not generally used for regulating purposes, but simply to add enough pressure to the dynamos to enable them to charge the batteries. In railway work, where the load fluctuates very rapidly, the booster is so constructed as to make the battery discharge when the load is heavy and charge up when it is light. In lighting plants, the booster is usually shunt-wound or compound-wound and is driven by a motor. Fig. 71 shows one scheme of connections. Only the essential parts are here shown, so as to illustrate the principles involved without confusing the diagram with the various instruments and switches. For this reason, also, a simple two-wire system is illustrated. *G* is the generator supplying current to the lamp load *L*. *A* is the battery and *B* a number of cells at one end, from which connections are brought out to terminals *c*. A sliding contact *d* makes connection between contacts *c* and the bar *e*, so that by sliding *d*, the number of effective cells and, hence, the voltage of the battery may be increased or decreased as desired. This arrangement is known as an **end-cell switch,** and the cells *B* are called **end cells.** *F* is a single-pole double-throw switch, by means of which the battery may be connected across *G* in series with the booster or directly across the line. In the figure, the switch is thrown up, as indicated by the dotted line, and the battery is being charged, because

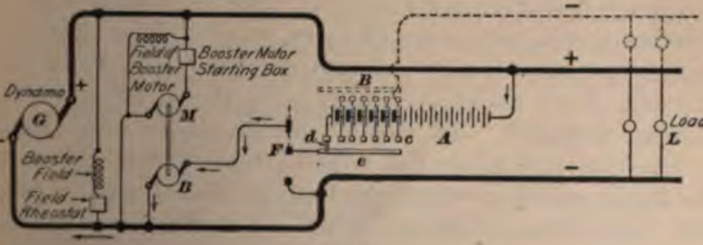


FIG. 71.

the voltage generated in the booster armature is added to that of the generator. When *F* is thrown down, the battery *A* discharges into the line and the voltage may be regulated by means of the end-cell switch.

65. In lighting installations, the necessary regulation can easily be effected by means of end-cell switches, because the load does not fluctuate with great rapidity, as in railway work. In most large plants, two end-cell switches are provided in parallel, as indicated in Fig. 71, the second switch being shown dotted. This allows two different voltages to be taken from the battery, or in case of heavy loads the two switches may be operated together as one switch.

66. Since the end-cell switches must carry the current output of the battery, they must be substantially constructed and have contacts that are sufficiently heavy to carry the current without heating. The sliding piece *d* generally takes the form of a crosshead, which is moved by a screw that is driven either by a hand wheel or by a small electric motor controlled from the switchboard.

67. From the above it will be seen that the storage battery may be made a very valuable auxiliary, especially in large lighting plants. It must be remembered, however, that such batteries are expensive, and the question as to whether it will pay to put them in, in any given case, is a thing that must be looked into carefully. In large city stations, it no doubt does pay, as is shown by the large number installed. In smaller plants, where they cannot receive the same amount of skilled attention that they do in the larger ones and where the load handled is not, at best, very large, it may often pay better to install a larger generating capacity than to use a battery.

ELECTRIC LIGHTING.

[illegible]

ARC LIGHTING.

1. Introductory.—[illegible] electric lighting [illegible] the methods of distributing the current [illegible] used. We will now take up the subject of arc lighting and consider the special methods [illegible]. The arc light, as before mentioned, was the first [illegible] public on a large scale [illegible] large voltaic battery for supplying the current [illegible] dynamo had been invented and the cost of generating electricity thereby greatly reduced, the arc light came into use commercially. At first it was used in [illegible] houses, but it was not long before it was used for street lighting, and it is now more generally used for [illegible] than any other form of illumination.

THE ARC.

OPEN ARCS.

2. General Features.—If two [illegible] connected to the terminals of a dynamo, as shown in Fig. 1, and first touched together and then drawn apart a short distance, say about $\frac{1}{8}$ inch, the current will continue to flow between the points and the carbons will become heated to an

For notice of copyright, see page immediately following the title page.

exceedingly high temperature. An **electric arc** may be formed in this way between any pair of conducting terminals; for example, an arc might be formed between two copper or iron rods. In this case, however, the metals would be rapidly melted away; carbon, therefore, is always used beca[illegible]se it is capable of standing the high temperature w[illegible]ut being consumed too rapidly. The color of the [illegible]ends on the material used for the electrodes; the arc [illegible]l between carbon is very brilliant, almost approaching sunlight. Violet rays are always present to some extent and give the arc light the well-known violet tinge that is often quite pronounced. An arc between copper electrodes is of a greenish tinge, while an arc between iron terminals is accompanied by a brilliant shower of sparks. An arc may be formed between carbon and copper or carbon and platinum, the carbon in both cases being used for the upper or positive **electrode**, as the terminals are often called, and the copper or platinum for the lower electrode. This arrangement has been used in a few isolated cases. For example, an upper positive carbon and lower copper electrode have been used in one form of locomotive headlight. It is important when this arrangement is used to see that the upper carbon is connected to the positive pole of the dynamo, so that the current flows from the carbon to the copper. If it flows the other way, the copper or platinum electrode will soon be burned away.

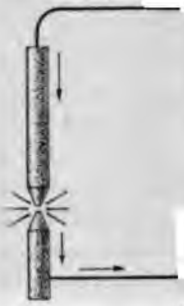


FIG. 1.

3. After the carbons have been separated for a time they take on the appearance shown in Fig. 2. This represents an open arc, or an arc formed in the open air, as distinguished from one that is formed in a confined space on the length of the arc; 45 volts may be taken as a fair average. This total voltage may be looked upon as made up of three parts: (*a*) That necessary to overcome the resistance of the carbons and the parts of the lamp mechanism through which the current has to flow; (*b*) that necessary to overcome the resistance of the carbon vapor between the electrodes; (*c*) that which multiplied by the current represents the energy necessary to volatilize the carbon.

The E. M. F. necessary to overcome the resistance of the carbons and lamp mechanism is not very large; in most lamps it will not be more than 5 or 6 volts, of which 3 to 3.5 may represent the drop in the carbons and the balance is in the mechanism and various contact resistances.

The E. M. F. necessary to overcome the resistance of the arc proper is also small, but depends to a certain extent on the length of the arc. In most cases it will not be more than 5 or 6 volts.

Since the voltage across the lamp is, say, 45 volts and the combined drop due to the resistance of the carbons, lamp mechanism, and arc proper is, approximately, 10 volts, it follows that the balance (about 35 volts) multiplied by the current represents the number of watts expended in bringing the carbon up to the boiling point and causing it to volatilize. This voltage is often spoken of as the counter E. M. F. of the arc, but this term is not so commonly used as it once was. It is evident that quite a large amount of energy must be expended to bring the carbon up to the boiling point, and it is now generally admitted that the large balance of voltage required over and above that necessary to overcome the various resistances is a consequence of the power necessary to volatilize the carbon. The above values of the voltage are fair average values for open-arc lamps operated with direct current, but they may vary somewhat with different makes of lamp. The actual voltage across the arc is continually varying when the lamp is in operation, but in a well-adjusted lamp it should not vary through wide limits.

7. Current.—Ordinary direct-current open-arc lamps are usually operated with current ranging from 6 to 10 amperes. Very common values for the current are 6.6 amperes for lamps giving 1,200 nominal candlepower and 9.6 amperes for those giving 2,000 nominal candlepower. The exact value of the current is different in lamps of various makes, but whatever it may be, it is essential that it be maintained at a constant value if the lamps are to work properly. If the current becomes larger than that for which the lamps are designed, they will overheat and the carbons will flame badly and the service will be generally unsatisfactory. Open-arc lamps may also be operated with alternating current, but they are not as satisfactory as those using direct current either as regards light-giving properties or general performance. In the case of the open alternating-current arc, both carbons become pointed or have very small craters, so that the light is thrown upwards much more than with the direct-current lamp. Also, since the current flows alternately in opposite directions, the rate of consumption of the two carbons is more nearly equal. Fig. 4 shows the general form of the carbons with an open alternating-current arc.

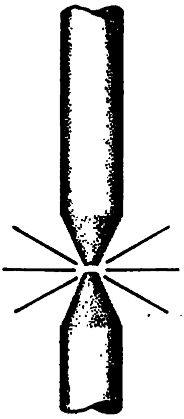


FIG. 4.

ENCLOSED ARCS.

8. General Description.—So far all that has been said with regard to the electric arc relates to arcs set up between carbon points placed in the open air. Within a comparatively recent date, **enclosed arcs** have been coming into extensive use, and bid fair to take the place of the open arc altogether. The enclosed arc differs from the ordinary open arc in that it is surrounded by a small globe that practically excludes the air. Fig. 5 shows the general arrangement of the carbons and the enclosing globe. *G* is a glass bulb from

5 to 6 inches long and about 3 inches in diameter, provided with an opening at each end. The lower end is held by a holder *C* and the lower edge *E* of the globe is ground so that but little air can get in at the bottom. In some makes of lamps an asbestos washer is used between the lower edge of the globe and the holder, to make a tight joint and distribute the strains on the glass. The lower carbon *B* is clamped in the holder *C*. The top of the bulb is ground smooth and supports a **gas cap** *P* with a hole in the center, through which the positive carbon passes. This plate is not fastened to the bulb, but is free to move about a little, and the hole in the center is just large enough to allow the positive carbon to move up and down freely. It is necessary to have the plate itself free to move, in order to get the carbons in line and prevent binding due to any slight irregularity in the carbon. Since the top of the glass and the lower surface of the plate are ground plane, little air can get in between them, and the only place where much air can enter the bulb is at the hole in the center of the top plate, through the small space between the carbon and the plate itself.

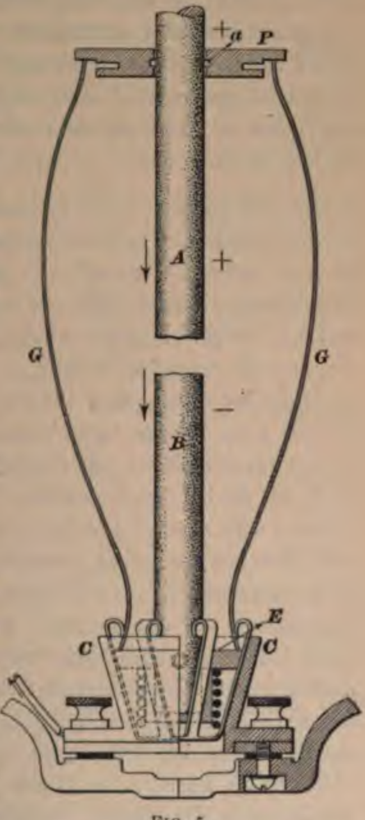


FIG. 5.

In the plate shown in the figure, there is an annular groove *a* around the carbon. This leaves less surface for the carbon to rub against and affords a space in which eddies are formed by the hot air passing up, thus further tending to keep out the cold air.

The above is intended merely to illustrate the general arrangement of the enclosed arc. The methods of holding the globe and the arrangement of the lower carbon holder differ in the various makes of lamp. A number of different styles of gas cap *P* are also in use, and the satisfactory operation of the lamp depends to a considerable extent on the design of this part.

9. As soon as [illegible] ca[illegible] are drawn apart an arc is formed, as in the ord[illegible] but the oxygen in the globe is soon burned out an[illegible] s present become rarefied, because the heat of [illegible] s them to expand and pass out. The globe is [illegible] nd there is always a small amount of oxygen p[illegible] is, however, is not enough to cause anything like [illegible] combustion that takes place in the case of [illegible] ope[illegible] he arc practically burns in a hot atmosph[illegible] o[illegible] carbon monoxide, carbon dioxide, and a sm[illegible] oxygen. This latter is just about sufficient to c[illegible] what carbon is thrown off and prevent its being deposited on the glass. If a lamp is in good condition, it will burn anywhere from 80 to 150 hours, depending on the design, without renewing the carbons. The bulb in time becomes coated with a light-colored deposit, sometimes mixed with a little carbon, which comes principally from impurities, such as silicon. This deposit does not cut off the light to any great extent if it is not allowed to become too thick. If the current passed through the lamp is excessive, the globes will become blackened or even melted. It is not usually advisable to burn these lamps more than 120 hours, as the deposit becomes so thick as to cut off a considerable amount of light.

10. Consumption of Carbons.—One of the most striking features of the enclosed-arc lamp is the slow consumption of the carbons. This is, of course, due to the absence of oxygen in the enclosing chamber. With the ordinary open arc the positive carbon is burned at the rate of about 1¼ inches per hour, while in an enclosed-arc lamp the consumption varies from .07 to .08 inch per hour. Enclosed-arc lamps may, therefore, be made to burn a long time without trimming; some have even been made to burn as long as 200 hours. This is one of the features that has led to the extensive introduction of this type of lamp. As in the open arc, the negative carbon of the direct-current enclosed arc burns about half as fast as the positive carbon; with alternating current, the consumption is more nearly equal.

11. Voltage and Current.—If the carbons of an open arc be pulled apart a distance more than enough to give from 40 to 45 volts across the arc, they will flame badly. On the other hand, the enclosed-arc lamp is operated with a long arc, about ⅜ inch, and it burns quietly. If a short arc is used in the enclosed arc, it is found that soot or carbon is deposited to such an extent that the lamp becomes useless; long arcs are, therefore, essential in these lamps. This allows them to be operated at a high voltage, and many of them take from 70 to 80 volts across the arc. They usually operate with a smaller current than the open-arc lamps, some of them taking as low as 2½ to 3 amperes. The advantage of using a high voltage and small current will be seen when we come to consider the operation of lamps in parallel on constant-potential circuits. Enclosed-arc lamps have also been built to operate on 220-volt circuits. Such lamps burn with a very long arc and are not quite as efficient as the ordinary 110-volt lamp, to which the above figures refer.

12. Character of Enclosed Arc.—Fig. 6 gives a general idea of the appearance of a direct-current enclosed arc. The student should compare this with Fig. 2. In the enclosed arc the carbons are separated by a wide gap, but the principal difference is that they do not take on the pointed shape. The ends of the carbons remain nearly flat and the arc keeps continually shifting around over the ends. The flat shape of the ends is, no doubt, due largely to this tendency of the arc to shift around. The light given out is soft and tinged with violet rays, having much less of the dazzling appearance so well known in connection with the ordinary arc. In the alternating-current enclosed arc, the lower and upper carbons are of about the same temperature and the light is thrown up more than with the direct-current arc. The carbons have, however, the flat-ended appearance and the arc shifts around even more than that of the direct-current enclosed arc.

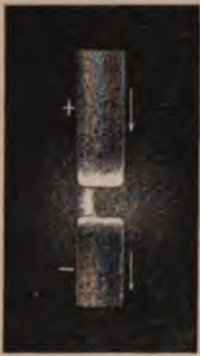


FIG. 6.

13. Open Versus Closed Arcs.—There has been, and still is, a great deal of discussion as to the relative advantages of open and enclosed arcs, especially for street lighting. For interior illumination, there can be little question as to the superiority of the enclosed arc. The light is very much softer and steadier and, in addition, the fire risk is less, because a large outer globe is usually provided in addition to the small enclosing globe. For street lighting, their advantages have not been quite so pronounced. Open-arc lamps have now been used for so many years for this work and have, on the whole, given such good satisfaction that they are not so easily replaced as in the case of interior lighting. At the same time, it is no doubt true that enclosed-arc lamps are ousting the older style open-arc lamps even for street-lighting work, and it is claimed that a considerable saving is effected by the change, principally because the cost of trimming and the cost of carbons is less. Of course, there is the renewal of broken inner globes in the case of the enclosed lamp, and also the additional work of keeping these globes clean, but even taking these items into account, the advocates of the enclosed-arc lamp for street lighting claim that a saving of $8 to $10 per year per lamp can be effected.

Wherever lamps must be operated by alternating current, the enclosed-arc lamp is extensively used and practically has the field to itself. The alternating-current open-arc lamp never proved a decided success. It usually made a loud humming noise and could not compete well with the direct-current arc lamp as an illuminant. The alternating-current enclosed-arc lamp has, however, been brought to such a state that it gives satisfactory service. The mechanism has been designed so that little noise is possible, and the enclosing of the arc prevents the humming of the arc itself from being loud enough to be objectionable. While, however, the alternating-current enclosed-arc lamp is much superior to the alternating-current open-arc lamp, it can hardly be said that it is capable of giving as good all-around service as the direct-current enclosed-arc lamp. No doubt, still further improvements will be made that will put it more nearly on a level with its direct-current rival.

ARC-LIGHT CARBONS.

14. Arrangement of Carbons.—In nearly all the lamps used for ordinary purposes, the carbons are arranged vertically, one above the other, as shown in Fig. 2. When arranged in this way, the top carbon should always be the positive one when direct current is used, otherwise the crater will be formed in the bottom carbon and most of the light will be thrown up instead of down. When lamps are first connected up, they should be allowed to burn for a short time, and if the crater makes its appearance in the bottom carbon, the connections to the lamp terminals should be reversed. Of course, with alternating current it makes no difference how the lamp is connected in circuit, as the current is continually reversing anyway and both carbons burn alike. It is an easy matter to tell when a direct-current lamp is correctly connected. Allow the lamp to burn for a short time, then switch it off and see which carbon remains bright the longer. The positive carbon is much hotter than the negative, hence the negative carbon is the one that becomes dull first.

15. For use in stereopticons and other projection apparatus, the carbons are often inclined at an angle, as shown in Fig. 7. The object in doing this is to allow more of the light from the crater to reach the lenses. In searchlights a similar arrangement is used, only the carbons are often slanted the other way and the light is reflected from a parabolic reflector or Ma irror, as shown in Fig. 8, which shows the arc pla e focus of a parabolic reflector *M*. The rays of light upon striking the mirror are reflected out parallel to each other, and as they are thus kept bunched together the light may be made to penetrate long distances. A small concave reflector is usually placed, as shown at *r*, to throw the rays of the arc that would ordinarily pass outwards back towards the main reflector.

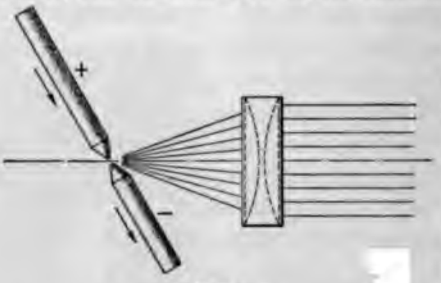


FIG. 7.

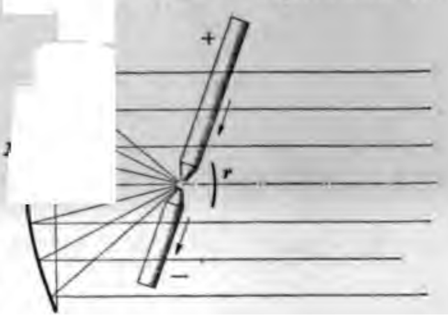


FIG. 8.

A parabolic ground-glass silvered mirror is used in the United States Navy, but for ordinary commercial work the Mangin mirror is used, as it is cheaper and easier to make. It is a glass mirror having two spherical surfaces *A*, *B* of different radii, as shown in Fig. 9. The back surface *A* is silvered and the rays are reflected

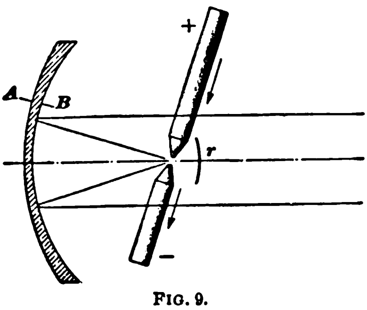


FIG. 9.

from it. As the glass is thicker near the edges than it is in the middle, the rays are there bent or refracted more than they are at the center, and by making the mirror of the proper dimensions it can be made to reflect the rays in a horizontal direction and give practically the same effect as the parabolic mirror.

Fig. 10 shows another arrangement of carbons that is used in searchlights. In this case the positive carbon is larger than the negative, and both carbons are arranged horizontally. The crater, therefore, points directly at the mirror. This is the arrangement now most extensively used in America both for naval and commercial work.

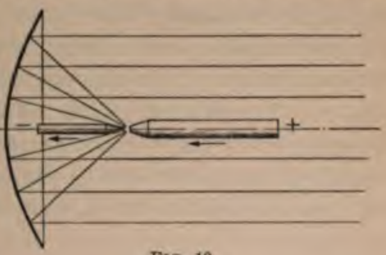


FIG. 10.

In all cases where arc lamps are used in connection with mirrors or lenses for projection work, it is essential that the arc be kept in the focus of the mirror or lens. The lamps must, therefore, be arranged to move the carbons towards each other as they are consumed, and they must do this in such a way that the position of the arc will not change. A lamp that does this is known as a **focusing lamp.** For ordinary lighting, it is not essential that the arc be kept in one place, so that the lower carbon is nearly always fixed and the arc maintained by allowing the upper one to move downwards as the carbon is consumed.

Fig. 11 shows a rather peculiar arrangement that is used for stereopticon lamps. Here the carbons are arranged at right angles to each other. The lamp mechanism moves *B* out in a horizontal direction, and *C* upwards as they burn away, so that the arc is always maintained in the same position at *a*. The position of *C* keeps it from interfering with the lens *l*, and

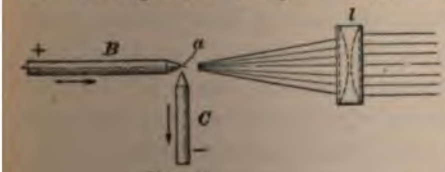


FIG. 11.

allows the greater part of the crater in the end of *B* to be exposed.

16. Composition of Carbons.—Carbons used for ordinary open-arc lamps in America are composed principally of petroleum coke. This is made from the residue left from the distillation of petroleum. It is ground up and mixed with a binding material, such as tar, or a similar substance, and is then molded into rods. Sometimes the rods are made in molds under a heavy pressure, but more frequently they are made by forcing the material through dies. The rods are then gradually dried and afterwards baked or fired at a high temperature. Gas-retort carbon has also been used for the manufacture of arc-light carbons, the exact composition used varying with different makers.

17. For enclosed-arc lamps a very much finer quality of carbon is required than for the open-arc lamp. If the carbons used in these lamps are at all impure, the impurities become volatilized and are deposited on the inner globe. Enclosed-arc carbons are, therefore, made principally of lampblack, which is practically pure carbon, and are considerably more expensive than the ordinary carbons made from petroleum coke. They must be straight and of uniform diameter, otherwise they will not pass through the cap of the enclosing globe properly.

The tendency of the arc to wander around the ends of the carbons has already been mentioned. This is especially the case with alternating current, and in order to hold the arc in the center, cored carbons are used. Fig. 12 shows a cored carbon; it is so called from the core *a* running through it. A small hole runs through the center of the carbon, and this is filled with a much softer material than the surrounding part. Some makers use cored carbons for both the + and the — electrodes of alternating-current lamps, while others use them for the + electrode only.

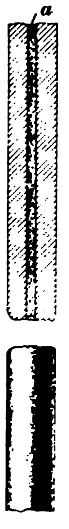


FIG. 12.

Cored carbons are used more particularly with alternating-current lamps, as the plain carbons usually give satisfactory service with direct current. Searchlights are almost wholly operated by direct current and the positive carbon is generally cored, as it is important to keep the arc in one place as much as possible.

Whatever kind of carbons may be used, it is essential that they be as pure and as uniform in quality as possible. If many impurities are present, they may interfere seriously with the quality of the light. Of course, impurities are especially bad in the case of the enclosed arc on account of the deposit caused on the inner globe, but even in the open arc they are objectionable because they volatilize at a much lower temperature than the carbon and thus tend to lower the temperature and light-giving properties of the arc. Hard spots in the carbons will cause uneven burning and carbons that are too soft are apt to flame badly. Hard spots will also give rise to hissing.

Carbons used for open-arc lamps are usually electroplated with a thin coating of copper. This increases their conductivity and makes them burn more uniformly and last longer.

PHOTOMETRY OF THE ARC LAMP.

LIGHT DISTRIBUTION.

18. The light given out by an incandescent lamp is fairly uniform in all directions, assuming, of course, that the lamp has no shade on it. On the other hand, the light given out by an arc lamp with a clear globe varies greatly in different directions. Since the manner in which an arc lamp distributes its light is of the greatest importance, it will be well to examine the peculiarities of some of the more important types. It will not be necessary here to go into the methods of measuring the light intensity. It is usually done by means of a Bunsen or similar photometer, with the arc lamp so arranged that its candlepower may be measured in any direction.

19. Before going into the subject of light distribution, a few points with regard to globes may not be out of order. Ordinary open-arc lamps used for street lighting are generally provided with clear globes. A clear globe will cut off from 6 to 10 per cent. of the light, and if it is dirty it will cut off more. Sometimes opal globes are used, especially if the lamp is used for interior work. An opal globe softens the light and does away with the sharp shadows that are always present with a clear globe. In other words, an opal globe alters the distribution of the light considerably and avoids the deep shadows underneath the lamp. At the same time, a globe of this kind cuts off from 30 to 40 per cent. of the light; in fact, if the globe is very milky it may easily cut off 50 or 60 per cent. In the case of the enclosed-arc lamp we have, in addition to the outer globe, the inner globe, and hence the amount of light cut off is somewhat increased. Reflectors are used much more largely with the alternating-current arc lamp than with the open arc, because the former tends to throw its light to a greater extent above the horizontal, and by using the reflector this light can be thrown downwards and utilized.

20. Open-Arc Direct-Current Lamps.—The distribution of light from an ordinary open-arc lamp is about as shown in Fig. 13. This represents the variation in the intensity of the light at different angles above and below the horizontal line passing through the arc that is located at *a*. The distance from *a*, measured along the radius at any given angle, is proportional to the candlepower of the lamp when viewed from that position. For example, the light reaches its greatest intensity at a point about 45° below the horizontal and then rapidly diminishes on both sides of this point. Directly above or below the arc there is, of course, little or no light, as the arc is obscured by the frame of the lamp and the carbons themselves. The open arc throws out comparatively little light in the horizontal direction, and the quantity of light thrown upwards is small. It is thus seen that the plain open-arc lamp using a direct current as it stands, without any reflector and with simply a clear-glass globe, gives a good distribution of light for street lighting because, on account of the formation of the crater in the upper carbon, it throws the bulk of its light downwards at an angle of about 45°, where it is most needed. This is one of the reasons why the direct-current open-arc lamp has proved so successful for street lighting. If the deep shadows directly under the lamp are objectionable, they may be softened by using a clear globe with the lower half ground.

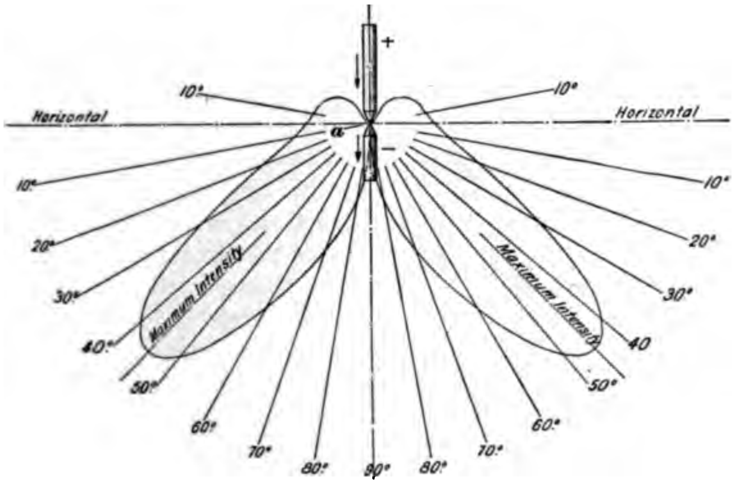


FIG. 18.

21. Open-Arc Alternating-Current Lamps. — The distribution from an alternating-current open-arc lamp is not of much practical importance because these lamps are now seldom used. It is, however, instructive to compare it with Fig. 13. Fig. 14 shows the general distribution from an alternating-current open arc, as determined by Uppenborn. It will be noticed that a great deal of the light is circuits. Curve *A* shows the distribution when the lamp is provided with an opalescent inner globe only; there is no larger outer globe. The student should compare this curve with that shown in Fig. 13 for the open arc. It will be noticed that with the enclosed arc, the light is of fairly large intensity through a considerable angle below the horizontal. In this case, the maximum value is approximately 360 candle-power and occurs about 30° below the horizontal. This is considerably less than the intensity given by an open arc, at about 40 to 45° below the horizontal, but the light from the latter falls off very rapidly on each side of the maximum point, whereas in the enclosed arc it is fairly well maintained through a considerable angle. Curve *B* shows the distribution when the lamp is provided with a clear outer globe in addition to the inner opalescent globe. The effect is to slightly cut down the intensity as a whole. Curve *C* shows the effect of using an outer opalescent globe. It is easily seen that the effect is to make the light approximately uniform in all directions at the expense of greatly cutting it down.

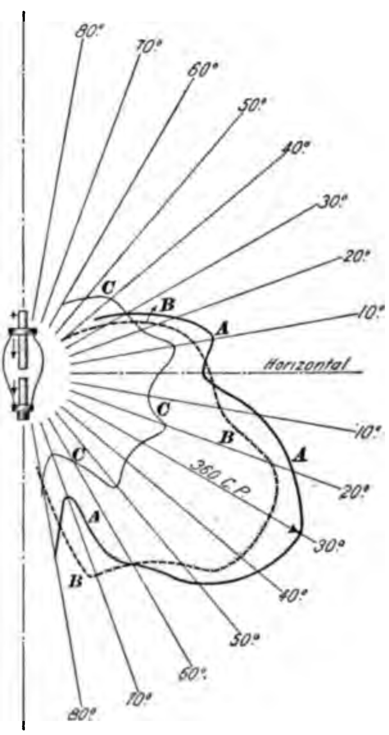


FIG. 15.

The distribution of light from an enclosed-arc lamp is subject to considerable variation. It depends to some extent on the shape of the enclosing globe and also on the thickness of deposit on it. It also depends on the position of the arc in the enclosing globe.

23. Enclosed-Arc Alternating-Current Lamps.—The direct-current lamp gives a better distribution for street lighting than the enclosed-arc alternating-current, and, on the whole, the latter is not quite as efficient as the direct-current. If, however, full benefit is to be obtained from the light given by the alternating-current enclosed arc, a reflector of some kind must be used. This is shown by the curves in Fig. 16. Curve *A* represents the distribution from an enclosed-arc alternating-current lamp that has an opalescent inner globe and a clear outer globe. It will be noticed that a large quantity of light is thrown above the horizontal, as in the case of the open-arc alternating-current lamp. Curve *C* shows the distribution when the same lamp is provided with a reflector. The curves show how the light that would ordinarily be thrown upwards and, hence, would be of little or no use for street illumination, is made available. Thus equipped with a reflector, the alternating-current arc makes a better showing against the direct-current. The alternating-current enclosed arc equipped with a reflector is rapidly finding favor as a street illuminant, though it may not be quite as efficient as the direct-current arc; its use in many cases so simplifies the outfit required at the station that the slight difference in the efficiency of the lamps themselves is more than made up.

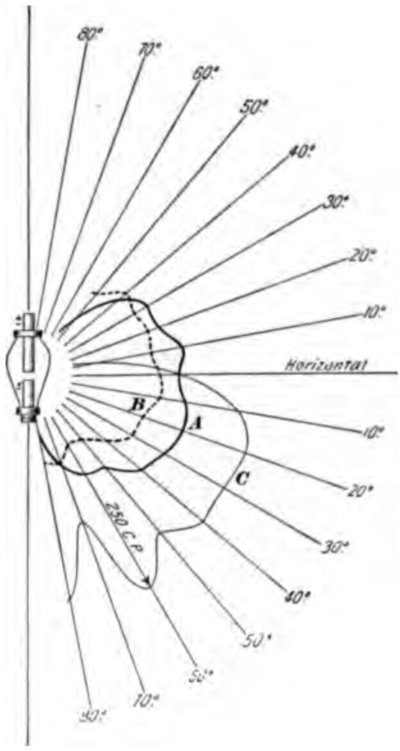


FIG. 16.

This will be more apparent later when we come to consider the various systems of supplying lamps with current. In Fig. 16, curve *B* shows the distribution given by an alternating-current enclosed-arc lamp when used with opalescent inner and outer globes.

CANDLEPOWER OF ARC LAMPS.

24. The candlepower of an arc lamp is a rather indefinite quantity. In making comparisons between different lamps, the only way to make such a comparison that is at all fair is to take the mean spherical candlepower of the lamps, i. e., what their candlepower would be if it were equal in all directions, instead of varying, as indicated by the curves just shown. In comparing incandescent lamps, it is usually sufficient to compare their mean horizontal candlepower as obtained by spinning the lamp, but in the case of an arc lamp the distribution is so irregular that the mean spherical candlepower must be taken. Again, the candlepower of an arc lamp as given out in the various directions is a difficult thing to measure accurately with the photometer. The arc always keeps shifting, and the intensity of the light is subject to such variations that a large number of settings of the Bunsen screen must be made to obtain anything like average results.

25. In the early days of electric lighting it was customary to speak of the ordinary lamp as giving 2,000 candlepower or 1,200 candlepower. The candlepower of these lamps was not nearly as high as this. It is barely possible that under exceptional conditions the light given out in the *maximum direction* might have reached these figures, but the average candlepower was nowhere near 2,000. About 375 to 450 would be nearer the mark. This old rating gave rise to a great deal of trouble, as customers were often told that the lamps should give 2,000 candlepower and that the lighting companies were not living up to their contract. It has become customary, therefore, to specify arc lamps as taking so many watts instead of supplying a certain number of candlepower. This is, generally, more satisfactory, because the watts can be measured at any time, to see if the contract is being lived up to. The lamp formerly rated at 2,000 candlepower has thus come to mean one that is supplied with 450 watts, and a 1,200 candlepower one that is supplied with 300 watts. The ratings 2,000 and 1,200 candlepower should never have been applied to these lamps in the first place, as they have absolutely no meaning. As ha ted, the mean spherical candlepower of an o rect-current open arc is, generally, somewhere 75 and 450 candlepower. The mean spherical ca represented by curve *A*, Fig. 15, is about 223; 181; curve *C*, 155. For the alternating-current presented by Fig. 16, the mean spherical ca curve *A* is about 140; for curve *B*, 114.

26. Power Consun er Candlepower. — The number of watts that must be supplied to the terminals of an arc lamp per mean spherical candlepower will depend on the construction of the lamp and on the conditions under which it is used. For example, when direct-current lamps are operated on 110-volt direct-current circuits, it is necessary to have a resistance in series to take up the voltage over and above the 80 volts required by the arc, and even if the line voltage were suited to that of the arc, a resistance would still be necessary to make the lamp regulate properly, as will be explained later. The waste in this resistance may amount to as much as 140 or 150 watts, and this lowers the general efficiency of the lamp. When lamps are operated in series, this resistance is not necessary and the waste in the lamp is less. An ordinary series open-arc lamp requires about 1.2 watts per spherical candlepower. A direct-current enclosed arc requires about 1.8 watts per spherical candlepower, not counting the power lost in the resistance. If a resistance is used, as in the case of the lamp operated on 110-volt direct current, the power consumption per candlepower will be 2.3 to 2.4 watts. For example, the lamp represented by curve *A*, Fig. 15, took 4.9 amperes at 110 volts or 539 watts, of which 147 watts were wasted in the resistance and 392 watts taken up at the arc. The lamp gave about 223 mean spherical candlepower; hence, the total number of watts per candlepower was $\frac{539}{223} = 2.4$. Not counting the loss in the resistance, the watts per candlepower would be 1.8, nearly.

The alternating-current enclosed-arc lamp requires about 2.4 watts per spherical candlepower, not counting the energy lost in the lamp mechanism. If an alternating-current lamp is run from constant-potential mains, the excess voltage can be taken up by a reactance, or choke coil, which wastes much less energy than a resistance. The energy wasted in the mechanism of a constant-potential, alternating-current arc lamp will not be more than half that of the direct-current lamp using a resistance. If we include the power lost in the mechanism in both cases, the alternating-current, constant-potential enclosed arc would require 2.45 watts, as against 2.3 watts required by the direct-current arc. If we use a shade on the alternating-current arc, the power consumption per candlepower delivered below the horizontal becomes much less; but in comparing the different lamps, we must take them all under the same conditions as nearly as possible.

27. The above figures are intended to give a general idea as to the efficiency and illuminating power of the various kinds of lamps, and represent average conditions. Of course, lamps may be met with that will vary considerably from the above. If we take an enclosed-arc lamp taking 450 watts and compare it with an open-arc lamp taking the same amount of power, we will find that the open-arc lamp will give a somewhat brighter illumination on the street. Notwithstanding this fact, the public, as a rule, does not object to the enclosed arc being substituted

TABLE I.

POWER CONSUMPTION OF ARC LAMPS.

Type of Lamp.	Total Watts Consumed.	Watts Consumed in Resistance or Choke Coil.	Watts at Arc.	Mean Spherical Candlepower.	Total Watts per Mean Spherical Candlepower.	Watts at Arc per Mean Spherical Candlepower.
Series open arc 2,000 nominal candlepower about 9.6 amperes at 50 volts............	460–480		450	375	1.3	1.2
Direct-current enclosed arc 110 volts 4.9 amperes, opalescent inner globe, no outer...............	539	147	392	223	2.4	1.8
Same with opalescent inner and clear outer globes.............	539	147	392	181	2.9	2.1
Same with opalescent inner and outer globes	539	147	392	155	3.5	2.5
Alternating-current enclosed arc 110 volts, opalescent inner and clear outer globes...	416	74	342	140	2.9	2.4
Same with opalescent inner and outer globes	416	74	342	114	3.6	3.0

for the open, because the light is much softer and steadier and the shadows are not so deep. As has already been pointed out, the enclosed arc is cheaper to look after on account of the long life of the carbons, and for this reason it is replacing the older style of lamps.

The preceding figures relating to arc lamps are here placed in the form of a table (Table I), for convenient reference.

28. The number of arc lamps required to illuminate a given space varies greatly and it is difficult to give any definite figures on this subject. Enclosed-arc lamps are now largely used for the interior illumination of mills and factories. The light from these lamps is steady and agreeable, and if they are provided with light opal globes or reflectors, a very even illumination may be obtained. In textile mills, the illumination must be very good; hence, more lamps are needed per unit of floor area than would be required, for example, in a foundry. Table II, based on values given by Uppenborn, will give a general idea as to the space that may be illuminated for each 450-watt lamp used.

TABLE II.

SPACE ILLUMINATED BY ARC LAMPS.

Space to be Illuminated.	Square Yards per 450-Watt Lamp.
Outdoor areas	2,000–2,500
Train sheds	1,400–1,600
Foundries (general illumination)	600–800
Machine shops	200–250
Thread and cloth mills	200–230

METHODS OF DISTRIBUTION.

29. We have considered the more important points relating to the arc itself, and it is now in order to consider the lamp proper. The arc lamp must, besides being arranged to hold the carbons in their proper position, be provided with a mechanism to start the arc, or "strike" the arc, as it is sometimes called, and also to feed the carbons together as they burn away. But before looking into the subject of arc-lamp mechanisms, it will be well to take up the methods used for [illegible]ing current to the lamps, because this has a bearing [illegible] style of mechanism used.

SERIES [illegible]IBUTION.

30. Most of the [illegible] used for street-lighting work are conne[illegible] For example, in Fig. 17, *A* represents an [illegible]o in the station and *l*, *l*, *l* are arc lamps situated [illegible]ent points on the street;

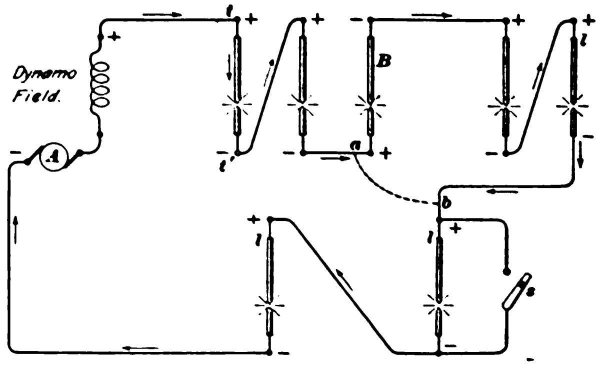


FIG. 17.

t, *t'* represent the terminals of the lamps, and are marked + and – to distinguish them from each other. The current flows through the lamps in the direction indicated by the arrows. The + terminal should in each case connect to the upper carbon and the negative terminal to the lower carbon. If one of the lamps *B* should be connected in the circuit backwards, as shown, the current would enter at the lower carbon and the lamp would burn upside down; in such a case the terminals should be changed so that the current will enter at the top carbon, as in the other lamps. It is evident that in a simple series circuit the current through all the lamps must be the same unless there is leakage to ground and across to the other line, as indicated, for example, by the dotted path *a–b*. There will be no leakage to amount to anything if the line is in proper condition, so that it may be generally assumed that the current through each lamp is the same.

31. Since each lamp requires a certain current for its operation, it is evident that the current in the circuit must be kept constant, i. e., the number of amperes must be kept the same no matter how many lamps are in use. If we had 10 lamps in operation, each requiring 45 volts pressure, the dynamo would have to generate 450 volts. Suppose now that 3 of the lamps are cut out by short-circuiting them—lamps in a series circuit must always be cut out by short-circuiting, otherwise the circuit will be broken. In practice, each lamp is provided with a switch, as indicated at *s*, which is used to cut out the lamp by short-circuiting it and allowing the current to flow past it. If the voltage remains the same, it is evident that the current will increase, because we have decreased the resistance of the circuit; if the current is increased, the lamps will perform badly and perhaps burn out. In order to keep the current the same, the voltage should be reduced to 7 × 45, or 315 volts, when the lights are cut out. This is done by providing the dynamos with an automatic regulator. In case the lamps are operated in series by means of alternating current, a special transformer or regulator of some kind is frequently used to keep the current constant.

The series system of distribution is very widely used for street lighting, and is, in fact, about the only system that can be used economically where the lights are scattered. As the same current flows through all the lamps, the system is operated by using a small current (usually from 6 to 10 amperes) at a high pressure. This calls for a small line wire (usually about No. 6 or No. 8 B. & S.), and thus requires but a comparatively small expenditure for copper.

32. Arrangement of Series Circuits.—If we take a simple series circuit, as shown in Fig. 17, the voltage generated by the dynamo will be the voltage per lamp multiplied by the number of lamps plus the voltage drop in the line. If the number of lamps operated is large, the voltage required becomes very high. Thus, in order to operate 75 lights, the machine must generate, roughly, 3,750 volts, allowing 50 volts per lamp, so as to include the drop in the line. Up to within a comparatively recent date, this was considered about as many lamps as could be operated from one machine, because of the difficulties of construction and operation for higher voltages. The result was that a station operating a large number of lights had to be equipped with a number of comparatively small machines, that were, at best, not very efficient. To overcome this, the so-called **multicircuit** machines were brought out, which are capable of operating 125 to 150 lights. The construction of arc dynamos has also been perfected to such an extent that machines are now built capable of operating 150 lights on a single circuit.

33. Multicircuit Series Machines.—Multicircuit machines are of two kinds, namely, those in which there are two or more circuits in series and those in which there are two or more circuits in parallel. The later styles of Brush machine are examples of the first kind. The new type of Western Electric machine is an example of the second. The simple, or older, type of Brush arc dynamo has already been explained. The newer and larger style is of the multipolar type, but is similar in principle to the old two-pole machine. The principal difference is in the arrangement of the circuit connections.

Suppose that *A* and *B* represent two of the commutators of a Brush machine. In the older machines they were connected in series, as shown in Fig. 18 (*a*), across a single circuit. The voltage between the terminals of the circuit *1–2* will therefore be equal to the sum of the voltages generated in the sections of the armature *A* and *B*. Suppose, however, that two series of lamps are arranged as shown in Fig. 18 (*b*). Here we have the same number of lamps connected in series as before, but they are divided into two circuits *1–2* and *3–4* and the pressure between points *1*, *2* is just one-half what it was before, because there are only one-half as many lamps connected between *1*, *2* that there were in the previous case.

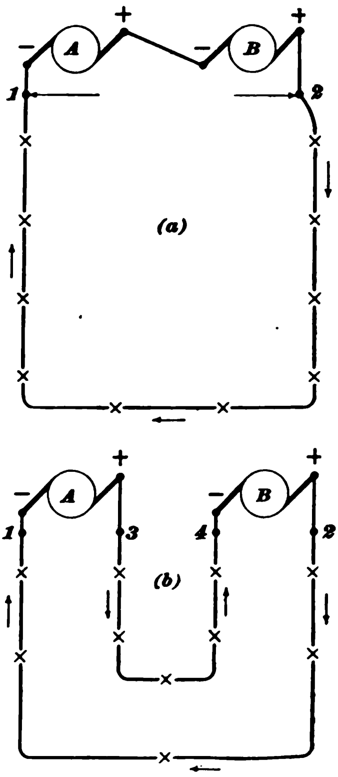


FIG. 18.

The whole object of this arrangement is to allow a large number of lamps to be operated in series, without introducing extremely high pressures on the line and dynamo. This may, perhaps, be more clearly understood by taking the example shown in Fig. 19. It would not be necessary to use a multicircuit arrangement for as small a number of lights as 10, but it will serve to illustrate the point. Allowing 50 volts per lamp, so as to include the line drop, we would require 500 volts for operating the single circuit in Fig. 18 (*a*). We can therefore represent the fall, or drop, in pressure from the + to the – terminal of the machine as indicated in Fig. 19 (*a*). Each section of the armature generates 250 volts, and as these are connected directly in series, we have 500 volts across the circuit.

In the second case, we have the state of affairs shown in Fig. 18 (*b*). Suppose that we take the point *1* as a starting point and assume that it is at zero potential. The armature section *A* raises the pressure to 250 volts, so that there is a difference in pressure of 250 volts between points *3* and *1*. The current then passes through the circuit *3*–*4* containing 5 lamps, and the pressure drops off as indicated. Armature *B* again raises the pressure 250 volts, so as to operate the 5 lamps in circuit *2*–*1*.

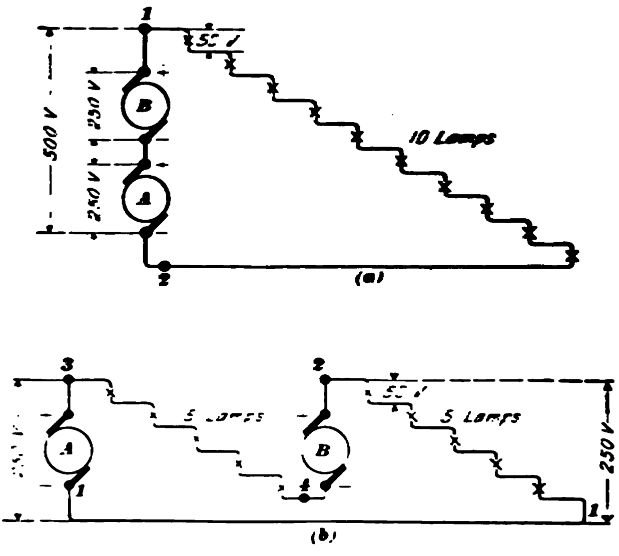


FIG. 18.

It is thus seen that the multicircuit arrangement shown in Fig. 18 (*b*) operates the same number of lights as in Fig. 18 (*a*), and the maximum pressure between the terminals of the dynamo or between the terminals of either of circuits is just one-half that in the single-circuit scheme ration. If, however, the circuit is opened at any , the pressure at the break will at once rise to a pressure that is at least equal to the total pressure that the machine is capable of generating, and will be as high as the pressure given by the single-circuit arrangement. This is because at the instant that the circuit is opened there is but a very small drop through all the lamps. Moreover, the sudden decrease in the current causes a high induced E. M. F. in the windings of the machine on account of the sudden decrease in the lines of force threading the field and armature, and the pressure obtained at the break may, in many cases, considerably exceed the full-load voltage of the machine.

34. Since, in the multicircuit arrangement, as used on the Brush machines, the several circuits are in series with each other, the current must be the same in all and only one regulator is necessary on the dynamo. Where two independent circuits are operated in parallel from the same machine, it is evident that the voltage applied to each of the circuits must be capable of independent regulation. For this reason, the Western Electric multicircuit machines are provided with two independent regulators, one for each circuit. Some of the larger Brush machines are arranged so as to operate four circuits, though any of these dynamos may be operated as ordinary single-circuit machines if desired.

PARALLEL DISTRIBUTION.

35. When arc lamps were first introduced, parallel distribution was not very common, but now a large number of lamps are operated in parallel on constant-potential circuits, both direct and alternating. The increased use of enclosed-arc lamps for store and factory illumination is largely accountable for this. Such places were usually equipped with low-pressure constant-potential plants for incandescent lighting, and series-arc lamps for interior work are more or less objectionable on account of the high pressures necessary for their operation. The series-arc lamp is, however, used for interior illumination in some large concerns where a large number of lights must be operated. Enclosed-arc lamps are operated in parallel by connecting them directly across the line, as indicated in Fig. 20. Each lamp is here provided with a double-pole switch and cut-out or branch block carrying fuses for protection in case a short circuit occurs in the lamp. Most lamps have a switch mounted on them, and it is only necessary to provide a separate switch, as shown, when it is wished to control the lamp from a distant point. Of course, the switch is arranged to open the circuit through the lamp, and not short-circuit it, as when cutting out a series lamp.

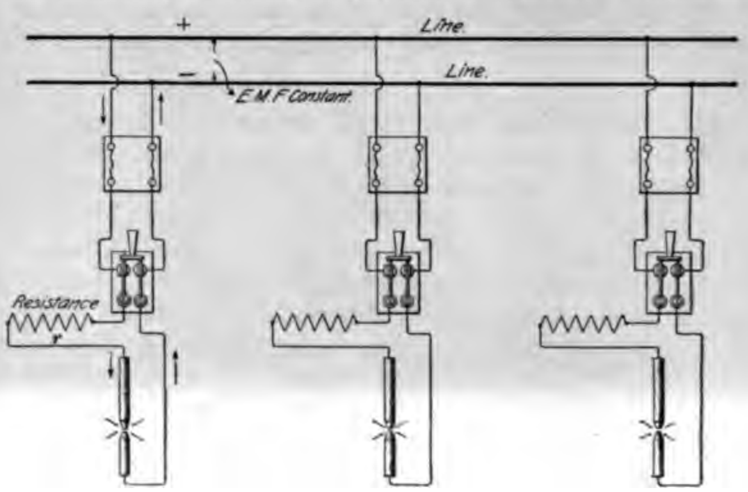


FIG. 20.

Fig. 21 shows the lamps connected to an ordinary 110-volt direct-current system. By using lamps with a slightly different mechanism, they may be operated from the secondary of a transformer, as shown in Fig. 22. When arc lamps are operated from constant-potential direct-current mains, it is necessary to connect a resistance *r*, Fig. 20, in series with the arc. This is necessary for two reasons. In the first place, the lamps will not regulate well without it, and in the second place, the voltages used on constant-potential circuits are usually considerably higher than the voltage required by a single arc lamp, so that the excess voltage must be taken up in a resistance.

If an arc lamp were connected directly to constant-potential mains, without the intervention of any resistance, its action would be unstable. If the current flowing through an arc increases, the resistance of the arc decreases, because the increased current causes the cross-section of the arc to increase. On the other hand, if the current decreases, the resistance of the arc increases. The consequence is that if the constant voltage of the mains was just equal to that required by the arc and if the current through the arc should, for any reason, decrease a little, the resistance offered by the arc would at once increase, thus causing a further decrease of current and increase of resistance, with the result that the arc would go out. On the other hand, an increase of current would result in a decrease of resistance,

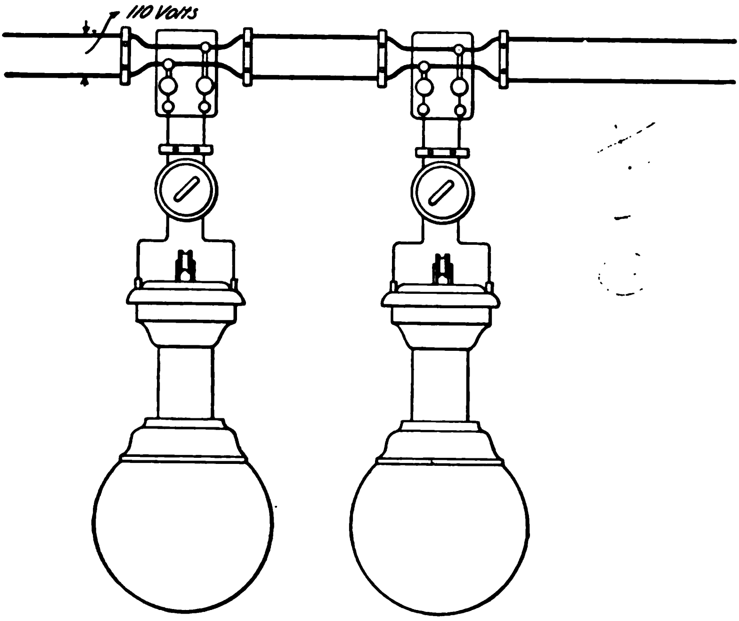


FIG. 21.

the resistance will decrease and, since the line voltage is constant, the voltage across the arc will be increased, thus compensating for the increased arc resistance. Also, if the current increases, the drop through the resistance at once increases and the voltage across the arc is lowered. In alternating-current lamps a *reactance* or *choke coil* takes the place of the resistance. This consists of a coil of wire wound on an iron core. When the alternating current passes through the coil, the changing magnetism set up generates a counter E. M. F. in the coil. The choke coil wastes less energy than the resistance, but, of course, it cannot be used with a direct-current lamp, as the direct current is not capable of setting up the alternating magnetism necessary to generate the counter E. M. F. The resistance or choke coil, as the case may be, is generally mounted in the top of the lamp and is arranged so that it will be ventilated, in order to insure cool running. Resistance coils in arc lamps are usually made of German silver and are in most cases wound on porcelain fittings.

36. Lamps in Multiple Series.—The use of the enclosed-arc lamp allows single lamps to be operated in parallel on 100- to 120-volt circuits without excessive waste. This is because these lamps take such a high voltage at the arc (from 70 to 80 volts). Open-arc lamps take only from 40 to 50 volts at the arc; hence, if these lamps were operated singly across 100- to 120-volt circuits, there would have to be from 60 to 80 volts taken up in the resistance. To avoid this, open-arc lamps were usually operated two in series, as shown in Fig. 23, thus requiring about 90 volts for the arc, and leaving only about 20 volts to be taken up in the resistance *R*. Quite a number of lamps were at one time operated in this

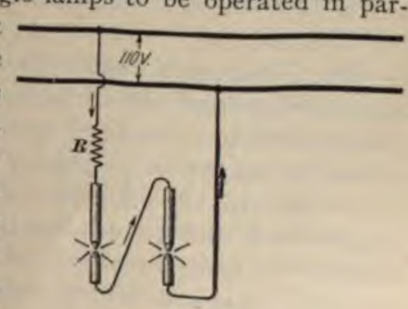


FIG. 23.

way, but the arrangement never worked entirely satisfactory. If one lamp failed to work properly, it affected the other, and the service was not as good as it should have been. This method of operating lamps has therefore been replaced by the use of the single enclosed-arc lamp connected directly across the mains.

The two methods of distribution to which we will confine our attention will be the series system, used almost exclusively for street lighting, and the simple parallel system, used principally for interior arc lighting.

ARC LAMPS.

37. The different makes and types of arc lamps in commercial use are so numerous that it is impossible to give a complete list of them here. This is, however, not necessary, because many of the types differ only in mechanical details and involve no new principles. Complete instructions concerning the different makes are furnished by the manufacturers, and all that is necessary is to point out the features peculiar to lamps adapted to the various kinds of service.

38. No matter what type of lamp is used, it must be arranged so that the carbons may be kept apart at the proper distance. In a few special cases, as, for example, in some searchlights or projection lamps, this is accomplished by hand. In all commercial lighting work the lamp must be provided with a mechanism that will feed the carbons together as they are consumed. In most cases, the lower carbon is fixed and the top one is fed down in such a way as to keep the arc of the proper length. When the upper carbon is released by the lamp mechanism, it is fed down by the attraction of gravity. Gravity is therefore the propelling power in most lamps, and the whole lamp mechanism is essentially a device first to separate the carbons and start the arc and then to release the carbon and allow it to feed down at the proper time. This feeding must be accomplished without disturbing other lamps on the same circuit. The mechanism generally consists of a clutch or clockwork controlled by electromagnets, the current in which depends on the condition of the arc and which releases the clutch or clockwork, thus allowing the carbon to feed down whenever the arc exceeds the length for which the mechanism is set.

As stated before, the mechanism must also be arranged so that the lamp will regulate without affecting other lamps on the circuit. This is comparatively easy to accomplish in the case of lamps operated in parallel, because the pressure across the mains is constant, and each lamp is independent of its neighbor. In the case of the series lamp, however, the current that flows through one lamp also flows through all the others, and each lamp must be arranged so as to feed when necessary, no matter what may be the condition of the others.

CONSTANT-POTENTIAL LAMPS.

39. The regulation of constant-potential lamps is usually brought about by an electromagnet or solenoid that is connected directly in series with the arc. This solenoid operates either a clutch or clockwork so as to feed the carbon when required. For example, take the simple arrangement shown in Fig. 24. This is not intended to illustrate any particular make of lamp, but simply to bring out some of the points connected with the operation of constant-potential lamps in general. By far the greater number of lamps in use employ a clutch rather than a clockwork feed. In Fig. 24, *t*, *t'* are the lamp terminals connected across a constant-potential circuit; *r* is the resistance inserted to take up the surplus voltage and to make the action of the lamp stable; *S* is a solenoid connected directly in series with *r* and arranged to suck up the core *c* when current passes; *d* is the clutch, which we have here shown simply as a washer with a hole a little larger than the rod *e*, to which the upper carbon is attached; *f* is a stop against which *d* strikes when the core *c* lowers a sufficient amount; *g* is the top (positive) carbon and *h* the lower (negative). The current enters at *t*, passes through *r* and *S* to the brush *k*, which makes a sliding contact with the carbon rod *e*. From *e* it passes to the top carbon *g*, thence to the lower *h*, and out at *t'*. The path is as indicated by the arrows. This is supposed to be a direct-current lamp; hence, the current should flow, as shown, so as to bring the crater in the upper carbon. With an alternating-current lamp, it would, of course, make no difference how the lamp was connected.

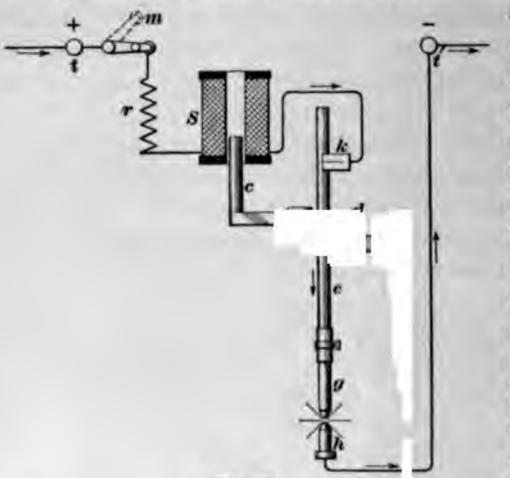


FIG. 24.

40. When the current is off, *d* comes down against *f* and is tilted so that *e* slides through until *g* strikes *h*. As soon as the current is turned on by closing switch *m*, the core *c* is at once sucked up to the full limit for which the lamp is adjusted. As soon as *c* moves up *d* tilts, as shown in the figure, and grips *e*, thus raising *g* and striking or starting the arc. As the carbons burn, the arc gradually becomes longer and, consequently, the resistance of the lamp, as a whole, increases. One fact that must not be lost sight of is that this lamp is connected in multiple across a constant-potential circuit; hence, as the arc lengthens, the current through the lamp is bound to decrease, no matter what current the other lamps on the same circuit may be taking. The result is that as the arc gets longer, *S* becomes weaker because of the smaller current and *c* lowers a little. When *c* has moved a short distance, *d* comes in contact with *f*, and as *c* drops still farther, *d* is tipped a little and allows rod *e* to slide through. As soon as the carbons come nearer together, the current at once increases, *c* is pulled up, and the rod is held until the current becomes small enough to allow it to feed again. In this way the carbon is fed down, a little at a time, and the feeding is brought about by the decrease of the current due to the increase in the length of the arc. It is thus seen that the regulation of a constant-potential lamp may be brought about by the use of a simple series solenoid, or magnet, and as a matter of fact the mechanism of these lamps is very simple; some of the modern enclosed-arc lamps have but little more mechanism than that indicated in Fig. 24.

SERIES-ARC LAMPS—OPEN ARC.

41. When we come to consider the regulation of series-arc lamps and the mechanism necessary for their operation, we have a different problem to deal with. In the first place, when lamps are run in series, the current is always maintained at a constant value, or it should be if the regulator on the dynamo works properly. It is evident, then, that a series magnet alone is not able to do the regulating, because its pull remains the same no matter what might be the condition of the arc. Again, there must be some device in the series lamp that will preserve the continuity of the circuit in case a carbon should become broken, fall out, or the circuit through the lamps become broken in any way. If such a device is not provided, an open circuit in the lamp will result in all the lights on the circuit going out. This device is called a **cut-out.**

42. Although the current through the arc remains constant in a series system, the voltage across the arc increases as its length increases, and this increased voltage is made to bring about the regulation. Suppose that we modify the simple lamp shown in Fig. 24 by extending the core *c* downwards and adding another solenoid *S'*, as shown in Fig. 25. We can also omit the starting resistance *r*, as this is to be a series lamp, and there will be no excess voltage to be taken up; the current is maintained at a constant value and resistance is not necessary to insure stability of operation. This second coil *S'* is to be wound with a large number of turns of fine wire, so that when it is connected in shunt across the arc, as shown, but a small current will flow through it. The coils *S*, *S'* pull *c* in opposite directions, and *c* will always take up such a position that the two pulls are balanced. The action of the lamp is, then, as follows:

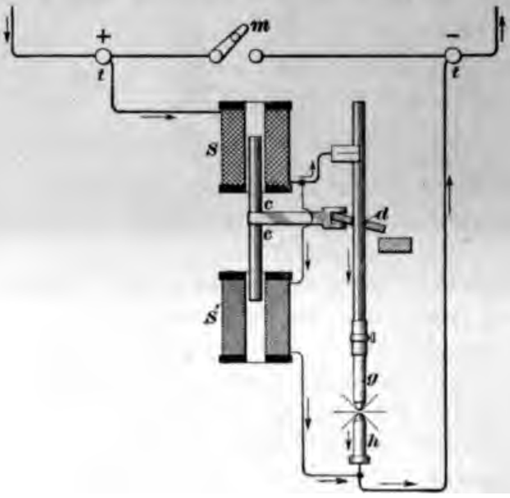


FIG. 25.

When the lamp is out, the carbons *g*, *h* are in contact. Notice that the switch *m* in this lamp is connected across the terminals, and in order to put out the lamp, *m* is closed. This is just the reverse of the constant-potential lamp that is operated in parallel. When the lamp is thrown into circuit, the main current passes between *g* and *h*, but since the carbons are in contact there will be little or no drop in potential between them and, hence, practically no current will pass through the shunt coil *S'*. The result is that coil *S* pulls up the plunger, and in so doing lifts the upper carbon and starts the arc. The instant, however, that the carbons *g*, *h* separate, current flows through S', because there is then considerable difference of potential between *g* and *h*. The result is that as the carbons are separated, the downward pull of S' becomes stronger until it finally balances the upward pull of S', when the arc remains stationary. As the carbons burn away, the arc becomes longer; hence, its resistance increases and the voltage across the arc increases. The pull of *S* does not change, because the main current is maintained constant by the dynamo. The pull of S' keeps increasing as the carbons burn away, and *c* is gradually pulled down until the lamp feeds. As soon as *g* feeds down the pull of S' decreases, because the arc shortens; hence, the position of *c* becomes again balanced, and so on, the plunger *c* moving back and forth through a small range between the coils. By properly adjusting the clutch, such a lamp may be made to keep the arc at the proper length within very close limits.

43. The student should carefully note the essential features of the above lamp, because practically all series lamps depend for their operation on the use of two coils. One of these, the series coil, carries the main current, and is opposed by the shunt coil, which carries a current depending on the length of the arc. The current in the shunt coil depends only on the length of the arc in each individual lamp and is independent of the condition of the other lamps. A lamp of this kind is known as a **differential lamp,** because the position of the core *c* depends on the difference in the pulls between *S* and S'. The simple series lamp shown in Fig. 25 is not provided with a cut-out, but the action of this device will be explained later when some of the different types of lamp are described. In some makes of lamps the coarse-wire and fine-wire coils are both wound on the same spools, and instead of using solenoids with a core that is drawn into them, the coils are provided with a fixed iron core and arranged so as to attract an armature that releases the clutch or clockwork mechanism, as the case may be. The Thomson-Houston (T. H.) and Brush lamps use two coils wound on the same core, and the armature operates a clutch. In the Wood lamp, solenoids are used very much as indicated in Fig. 25, and these lamps are made for either a clockwork feed or a clutch feed. In lamps having a clockwork feed, the rod that holds the upper carbon is usually provided with a rack cut along one side. This rack engages with a gear-wheel that is held from turning by means of a ratchet wheel and pawl. The frame on which these gears are mounted is pivoted, and its movement is brought about by the controlling magnets or solenoids. When the frame is moved by the action of the shunt magnet, the pawl is thrown out of interference with the ratchet wheel and the lamp feeds. The movement at any one feeding is very slight, and the carbons approach each other so gradually, if the lamp is properly adjusted, that a steady light is the result. The feeding mechanism of a clockwork lamp is slightly more complicated than that of a clutch lamp. In the latter, the carbon rod must be kept clean and bright, or else the clutch will not act properly. If, however, a clutch lamp is looked after as it should be, it will feed smoothly and give good results. The use of clockwork mechanisms is not as common as it once was, and practically all the modern lamps are operated by a clutch of some kind.

EXAMPLES OF ARC LAMPS.

CONSTANT-CURRENT SERIES LAMPS—OPEN ARC.

44. The constant-current series arc lamp using direct current and burning with an open arc has in the past been the style of lamp almost universally used for street lighting. There are thousands of these lamps in use, and notwithstanding the fact that the regulating mechanism of some of them is more or less complicated, they have given very service and their general design has been changed ittle. It is now customary to run more lamps on a it than was once the case; hence, the voltage of the its is higher, and it is necessary to provide the lamp anism with better insulation than was used in the older s. The design of the clutch has also been fied from time to time, but as a whole the anism of these lamps remains about the in principle as it was when they were ntroduced. The open arc is being grad- ousted for street lighting by the enclosed put as there are still very large numbers e former in use, it will be necessary to in a few of the more important types. this purpose we will select the Brush, . H. (Thomson-Houston), and the Wood s, as these have been more largely used any others.

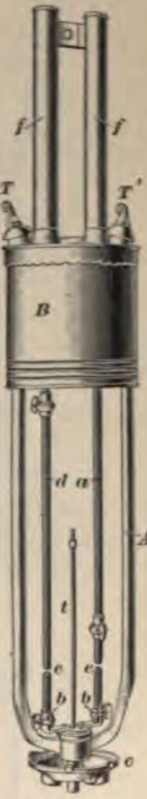


FIG. 26.

. When an open-arc lamp is required to all night, it is necessary to provide it two carbons, arranged so that when one isumed the other will start up. Fig. 26 s a Brush double-arc lamp for all-night ng. This view shows the lamp with the removed and with one pair of carbons y consumed. As soon as the carbon gets to its lowest point, the rod *d* starts ng, and the other pair of carbons are imed. In order to obtain a long life for arbons, some companies use single lamps, nstead of the ordinary $\frac{7}{16}$-inch or $\frac{1}{2}$-inch l carbons, they use $\frac{5}{8}$-inch or even larger. This results ong life, but the large carbons are apt to cast objec- ble shadows. Another scheme for securing long life he carbons of open arcs is to use flat carbon plates, this, also, has the bad feature of giving poor light bution.

46. The Brush Arc Lamp.—The general appearance of this lamp is shown in Fig. 26, which will serve to illustrate the appearance of all the lamps of this class. *A* is the frame carrying the lower carbon holders *b*, *b* and the globe

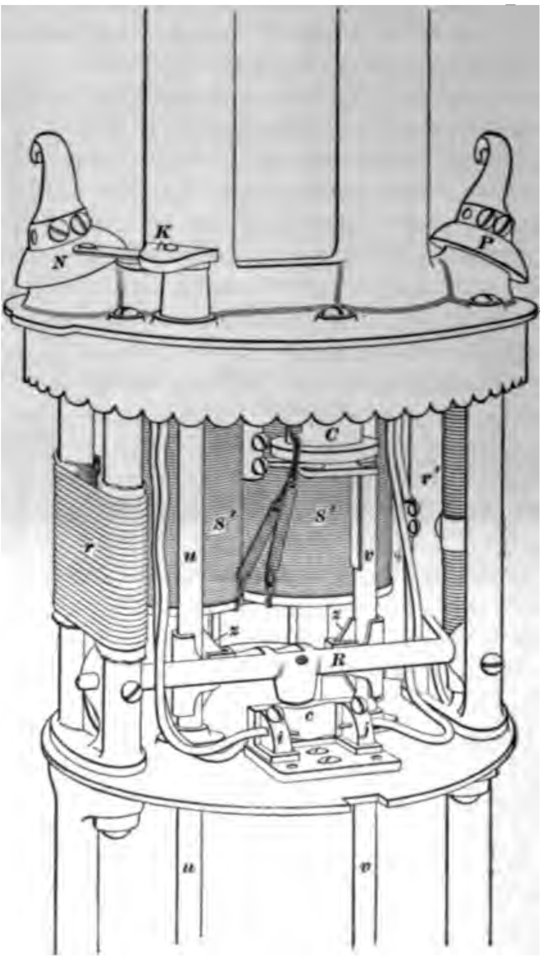


FIG. 27.

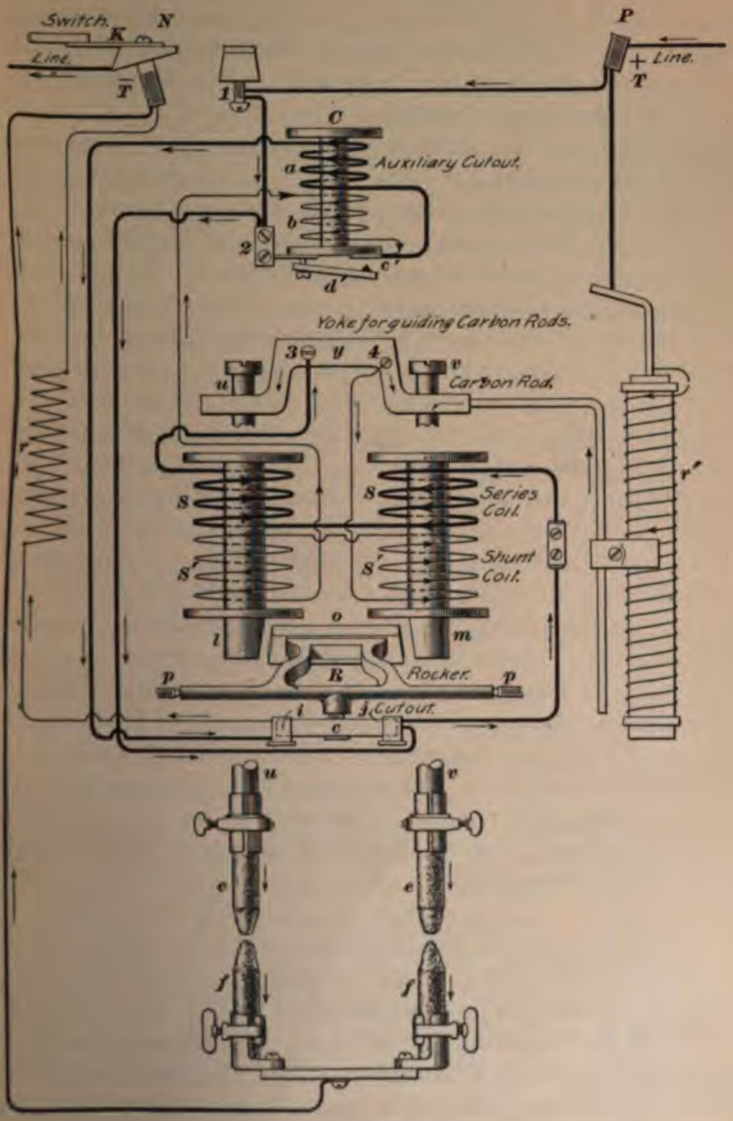

Switch.
K
N
Line.
T
1
P
+ Line.
T
C
a
Auxiliary Cutout.
b
2
c′
d′
Yoke for guiding Carbon Rods.
3
y
4
u
v
Carbon Rod.
r
r″
S
S
Series Coil.
S′
S′
Shunt Coil.
l
o
m
p
R
Rocker.
p
i
j
Cutout.
c
u
v
e
e
f
f

FIG. 28.

holder *c*; *B* is the cover for protecting the lamp mechanism; *a* is one of the carbon rods carrying the upper carbon holder. When the lamp is newly trimmed, these rods push through the case and are protected by the chimneys *f*, *f*. *T*, *T'* are the lamp terminals

Fig. 27 shows the relation of the parts of the lamp and Fig. 28 the connections. The coils *S*, *S'* and *a*, *b* are really wound on top of each other, but we have here shown them side by side for the sake of clearness. *P* and *N* are the positive and negative terminals of the lamp. The poles of the regulating magnet are at *l*, *m*; and *o* is the armature that moves up and down with the rocker *R* hinged at the points *p*, *p*. The clutches are not shown in Fig. 28, but they can be seen at *z*, *z*, Fig. 27. Their operation will be described later. The positive and negative carbons *e*, *f* are attached to the carbon rods *u*, *v*. When no current is flowing through the lamp, the armature *o*, Fig. 28, and the rocker *R* are in the lowest position, and the strip *c* comes in contact with the terminals *i*, *j*, thus cutting out the lamp and allowing the current to take the path *P*-*1*-*2*-*j*-*i*-*r*-*N*. *C* is an auxiliary cut-out that is intended to cut out the lamp whenever the pressure across the arc exceeds 70 volts. It consists of a magnet provided with two windings *a* and *b*, connected as shown, and a pivoted armature *d'* that makes contact at *c'* when the magnet acts. A small amount of adjustable resistance *r'* is in shunt with the series magnet *S*. By regulating this resistance, the pull of the series magnet may be adjusted; *r* is another small resistance connected in series with the cut-out *c*.

47. The action of the lamp will be understood by referring to Fig. 28. First we will suppose that the lamp is connected in circuit but is short-circuited by the switch blade *K* on top of the lamp being on contact *1*. The current then flows directly across from *P* to *1*, thence through *K* and out on the line. Under these circumstances no current flows through the mechanism, the armature will be down, the carbons in contact, and piece *c* will connect *i* and *j*. Now, suppose switch K to be opened. The current will then take two paths as follows: $P-r'-y-u-c-f-N$ and $P-1-2-j-i-r-N$. However, since S, S are connected in shunt with r', a portion of the current will flow through the series coils, taking the path $1-2-j-S-S-y$, and the armature will be lifted, thus separating the carbons and establishing the arc. As soon as the armature is raised, the contact c leaves the terminals i, j, and the current passing through r is interrupted with the exception of the small current that passes through the fine-wire coils S', S'. The clutch has now lifted the carbons and the lamp is in operation. One end of the fine-wire coil connects to the upper carbon, as indicated at 4, and the shunt current takes the path $4-S'-S'-b-c'-a-i-r-N$. It is thus seen that the coils S', S', and b are in series and are connected in shunt with the arc. Coils a and b tend to raise the armature d', but the current flowing under normal conditions is not sufficient to actually raise it. It should be noticed that the current circulates around S', S' in a direction opposite to that in S, S.

48. As the carbons burn away and the arc becomes longer, the current through the shunt coils increases, thus making the poles of the controlling magnet weaker and allowing the armature and rocker to gradually drop down. This lowering continues until the clutch releases and allows the carbon rod to slide down a little.

Fig. 29 shows a form of clutch used in this lamp. The piece a rises and falls with the rocker, and when it is raised the piece b is clamped against the carbon rod by means of the small lever d, and the movement of the armature lifts the whole rod. When a descends, because of the magnets becoming weaker, the whole clutch and rod move down until the piece e strikes the plate f. The piece g then remains stationary, while a moves down a little farther, thus moving the small lever d and unlocking the clutch.

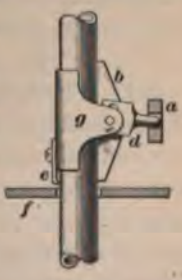


FIG. 29.

49. Suppose now that a carbon rod should stick in some way and fail to feed properly. The arc would gradually become longer and the voltage across it would increase until the current in the shunt circuit became much larger than the normal amount; this would cause the armature d' of the auxiliary cut-out C to be drawn up and contact made at c'. The current would then take the path $P-1-2-d'-c'-a-i-r-N$; the series and shunt coils would both be cut out, but the current flowing through a would hold up d'. The cutting out of the main coils would cause the rocker to drop and c would then come into contact with i and j, thus cutting out the auxiliary cut-out. If the dropping of the rocker frame should make the carbons come together, part of the current will pass through the series coils by the path $2-j-S-S-3-u-e-f-N$, because in the other path we have the resistance r. The result is that the lamp will start up again. If the resistance r were not used, the path $2-d'-c'-a-i-N$ would be of low resistance compared with $2-j-S-S-3-u-e-f-N$, and the lamp would not relight; hence, the use of the resistance r. If a carbon should become broken or fall out, all the current would for an instant pass through the fine-wire coils; hence, d' would at once rise and cut out the lamp. Of course, in this case c would come into contact with i and j and remain there, because the carbons could not come into contact again and allow the lamp to relight. If no cut-out were provided, there would not only be danger of a break in the circuit, due to the carbons being broken or failing to feed, but in addition the shunt coils would be burned out because the whole current would, under these circumstances, pass through them.

50. From the above description, it will be seen that this lamp works on the differential principle. When the lamp is not in operation, the carbons are together. As soon as the current passes, the series coils separate the carbons, thus starting the arc. The regulation is then brought about by the opposing action of the shunt coil causing the release of the clutch.

THE THOMSON-HOUSTON (T. H.) LAMP.

51. The Thomson-Houston open-arc series lamp is one that has been very largely used for street lighting on constant-current circuits. Notwithstanding the fact that the mechanism of this lamp is somewhat complicated and contains a large number of parts, it has given, on the whole, very good service; in fact, it may be said of most of the common types of constant-current lamps that although the conditions under which they must work are trying, they have given good service. The T. H. lamp has been changed comparatively little, as regards its main features, since it was first brought out. Some of the smaller details, such as the clutch, cut-out contacts, etc., have been changed, but the general arrangement has remained much the same. In the later lamps the insulation of the frame has been improved, owing to the fact that more lamps are now run on a circuit than formerly and the pressure applied to the circuits is correspondingly higher.

52. The T. H. lamp differs considerably from the differential lamp just described. The series coil is used only to start the arc, and when the lamp is in operation under normal conditions, no current flows through it. The regulation is effected by means of the shunt coil alone, and when the lamp is not burning the carbons are separated instead of being together, as is the case with most lamps. Fig. 30 (*a*) and (*b*) shows the mechanism of the T. H. double lamp, but for the present we will confine our attention to Fig. 31, which shows the connections and the general arrangement of the essential parts. This figure is intended to show only the principle of operation and is not supposed to be an exact illustration of the parts of the lamp itself, as some of the minor parts have been omitted in order to make the diagram as simple as possible. *A* and *B* are the + and − terminals in the shape of hooks, so that the suspending wires may also be used to conduct the current into the lamp; *E E* is the carbon rod carrying the upper carbon *m*; the lower carbon *n* is supported by the lamp frame, not

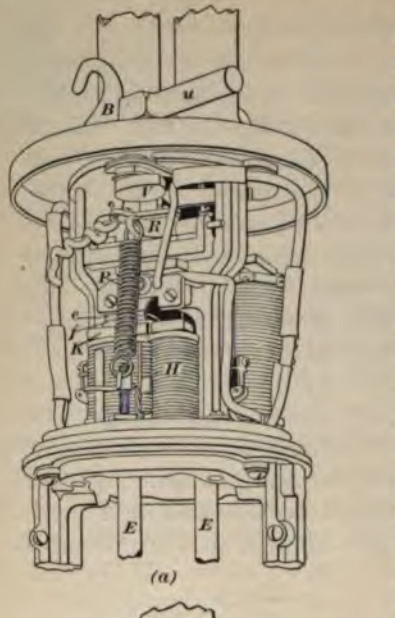


FIG. 30.

shown in the figure; R is a rocker frame pivoted at x and carrying an iron armature O. This latter has two holes in it, through which the conical pole pieces of the magnet project when the armature is pulled down. When the lamp is not in operation, this frame is held at its highest position by the adjustable spring P; the movements of the rocker are steadied by the dashpot C; s is the series coil wound over the shunt coil M; there are two spools side by side, as shown in Fig. 30; H is a small coil in series with the carbons. H is called the starting coil, and its office is to cut the series coil s into or out of action. It is provided with a movable armature K, on which is mounted the insulated contact f tipped with silver; e is another silver-tipped contact connected to the point c. When no current flows through H, e and f are in contact; p and r are the cut-out contacts, the action of which will be described later. L is the clutch and its action is very similar to the one just described for the Brush lamp.

53. We will first consider the operation of the lamp nder ordinary conditions. In Fig. 31 it will be noticed at the clutch *L* and frame *R* are up and that the car- ons are drawn a short distance apart. In order that

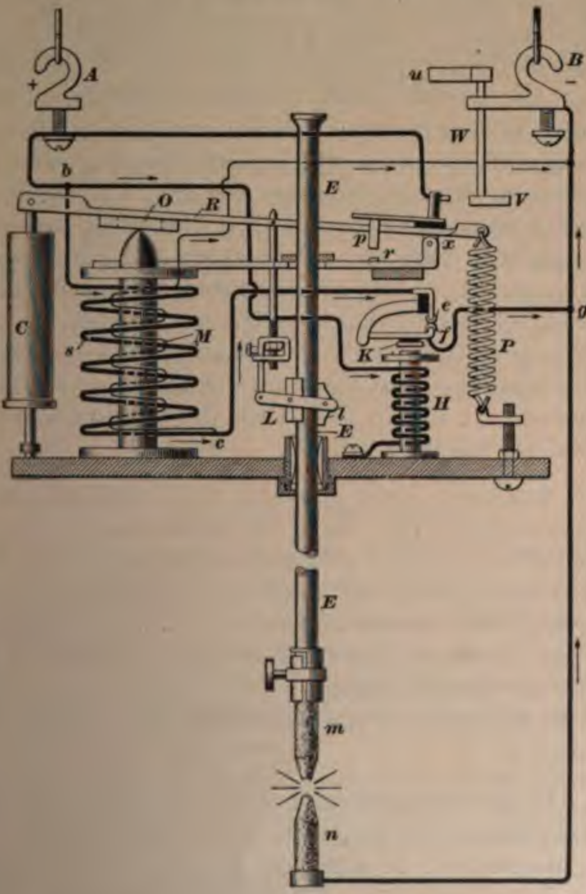


Fig. 31.

e lamp may be started, *m* must be lowered so as to uch *n*, and this is accomplished as follows: At the instant at the current is turned on, *e* and *f* are in contact, cause no current is flowing through *H*; hence as soon as the current passes, it takes the path *A–b* through the series coil *s* to *c–e–f–g–B*. Practically no current would go from *c* through the shunt coil to *B* because of the high resistance of this path compared with the other. As soon as the current passes through *s*, the rocker is pulled down and the clutch is released, bringing the carbons in contact and allowing part of the current to take the path *A–b–H–E–m–n–B*. As soon as current passes through *H*, the armature *K* is attracted, thus separating *e* and *f* and cutting off the current through the series coil *s* with the exception of the small current through the shunt coil *M*. The result is that the rocker rises and carries with it the upper carbon, thus separating the carbons and starting the arc. As soon, however, as the carbons are separated, there is considerable difference of potential across the arc; hence, the shunt coil *M* takes its normal current and holds the rocker at the proper point to give the length of arc for which the lamp is adjusted. It is thus seen that the series coil is cut out after the arc has been started.

54. The lamp is now supposed to be burning, and as the arc grows longer the pull of the shunt coil increases and the rocker is gradually pulled down until the shoe *l* of the clutch comes against the stop, and any further movement causes the rod *E* to slide down a little. The pull due to the shunt coil decreases with the shortened arc, and the rocker rises to its normal position. The feeding is thus brought about by the action of the shunt magnet working against the spring *P*.

55. If the carbons should stick and fail to feed, the arc will gradually grow longer until the pull exerted by the shunt magnet will be sufficient to bring the cut-out contact *p* down against *r*. The current will then take the path *A–p–r–E–m–n–g–B* in preference to passing through *H*. *K* will then rise and bring *e* and *f* in contact. The current will then take the path *A–b–s–c–e–f–g–B*; the series coil will hold down the armature and the lamp will be cut out unless the movement of the rocker should release the rod and allow the carbon to feed, in which case the lamp will continue to burn and rocker *R* will rise again, thus separating *p* and *r*.

56. If a carbon should fall out, the current through the shunt will suddenly increase and the current through *H* will be interrupted, *R* will be pulled down, and *K* will rise the final result being that the lamp is cut out.

57. When the lamp is to be switched out, the switch *W* is used. This switch takes the form of a cam *V* operated by the lever *u*, seen at the top of the lamp, Fig. 30. When the handle is turned to one side, the cam comes against the casting that carries the upper cut-out contact, and thus establishes a short circuit from terminal to terminal. Fig. 30 shows the general arrangement of the mechanism of this lamp. The lettering of the parts corresponds to that given in Fig. 31, so that they may be readily identified.

THE WOOD ARC LAMP.

58. This lamp operates on the differential principle and has been made both for clockwork and clutch feed. In the clockwork lamp the carbon feeds down whenever the movement of the rocker throws the pawl out, so as to allow the clockwork to operate. In the clutch lamp the movement of the rocker controls the clutch in much the same way as for the lamps already described.

Fig. 32 shows the general scheme of connections for a Wood lamp. Here the series coils *M* are arranged vertically above the shunt coils *S*. There are two series and two shunt coils. Two plungers connected by a crosspiece *g* are moved up and down by the coils, or solenoids, as described in Art. **42.** This armature moves a pivoted frame, not shown in the sketch, and thus brings about the regulation.

59. When the lamp is not in operation, the carbons are together and the plungers are at their lowest position.

When this is the case, pin *d* rests on spring *e*, which is in electrical connection with the framework and the carbon rod *h*. When the current is turned on, it takes the paths *A-p-d-e-R-B* and *A-p-k-l-M-M-m-n-B*. The resistance *R* is in itself small, but it is fairly large compared with that of the series coils *M*, and enough current will take the path through the series coils to lift the plungers and start the arc by separating the carbons. At the same time, contact is broken between *d* and *e*, so that all the main current passes through the series coils. The shunt coils *S* are connected across the arc, and as soon as the arc is started, they set up a pull in opposition to the series coils. When the arc has burned to a certain length, the plungers are pulled down enough to allow the carbon to feed. The action of the lamp, as a whole, is almost identical with that of the elementary lamp described in Art. **42.**

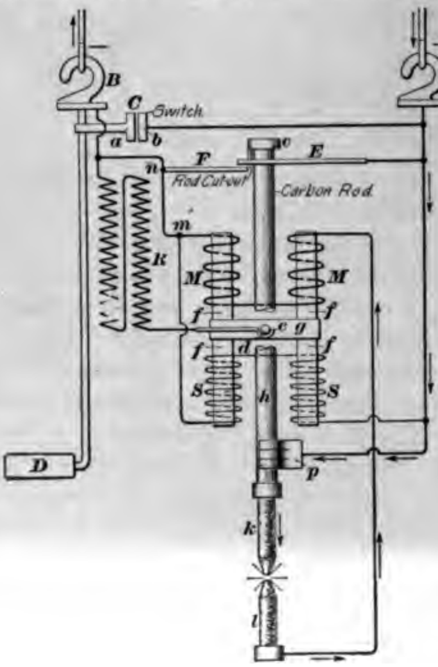


FIG. 32.

60. If the rod should stick, the arc gradually grows longer until the pull of coils *S* brings *d* down against *e* and thus cuts out the lamp. The object of using the resistance *R* is to enable the lamp to start up. If *R* were not present, the resistance of the path *p-h-d-e-B* would be so low compared with the path *p-h-k-l-M-M-m-n-B* that not enough current would flow through the series coils to start the lamp. This lamp is also provided with a rod cut-out, as shown at *E*, *F*. This short-circuits the lamp when the carbons have become nearly consumed. *C* is a hand switch operated by turning the handle *D*; it is used to cut the lamp out of the circuit whenever desired. When the handle *D* is turned, *a* and *b* are brought into contact, thus making a direct connection between *A* and *B*.

61. The above descriptions of three of the leading styles of constant-current series lamps will give the student an idea as to the main features of such lamps. It should be noticed that in all of them the arc is started by means of a series coil and that the feeding is regulated by means of a shunt coil. Most of the series lamps take about 9.6 amperes for the 2,000 candlepower size and 6.6 amperes for the 1,200 candlepower size. The voltage across the arc is from 40 to 50 volts and the carbons are generally $\frac{7}{16}$ inch, $\frac{1}{2}$ inch, $\frac{9}{16}$ inch, or $\frac{5}{8}$ inch in diameter.

CONSTANT-CURRENT SERIES LAMPS—ENCLOSED ARC.

62. Comparison Between Open and Enclosed Arcs. Up to within a comparatively recent date, the open-arc series lamp had the field of street lighting practically to itself. The constant-current enclosed-arc lamp is, however, now being extensively installed. It is used nearly altogether for new work, and is replacing the older open-arc lamp in many places. The reason for this is not that the old lamps were unsatisfactory in operation, because they have been operated for years and, taking everything into consideration, have given admirable service. Neither does the enclosed arc give more light than the open lamp; in fact, it does not give quite as much for the same amount of power consumed. Even assuming that the arcs themselves give as much light, the use of the two globes in the case of the enclosed arc cuts down the amount of light more than does the single

globe that is used with the open arc. This, how
counterbalanced by the more agreeable characte
light given by the enclosed arc. The strong con
noticeable with the open arc are softened down,
change from open to enclosed arcs is one that is g
popular, even if the intensity of illumination is s
reduced. The true reason of the change is, howe
the enclosed arcs are cheaper to operate.

63. Voltage Required by Series Enclosed-Arc
As stated previously, the enclosed arc is much lon
the open arc. This is necessary because the carbor
become pointed, there is no well-defined crater, and
bons must be separated considerably to allow a pr
tribution of light. Also, a short enclosed arc will
well, owing to the deposition of carbon on the carbo
These lamps, therefore, take a rather small current,
voltage across the arc is high. This is a decided a
where lamps are operated in parallel on constant-
systems, where the pressure is nearly always higher t
actually required by the lamp and the excess volta
be taken up by a resistance or choke coil. When, l
it comes to operating lamps in series, the high volta
the arc becomes, to a certain extent, a disadvant
means that for a given number of lamps operated
cuit, the pressure at the terminals of the circuit
higher in case enclosed arcs are used. This makes
cult to operate a large number of lamps from one
but by using the multicircuit arrangement, the
applied to each circuit may be kept down. C
current arc machines are now built to generate as
11,000 volts, which is about equivalent to 150 enclo
It is quite common to find as many as 100 lamps
on a single circuit. It must be remembered, howe
where these high voltages are used, the line insulati
be thoroughly good, and attempts to use these p
upon old lines having poor insulation have resulte
tinual trouble, to say nothing of the danger involve

64. Alternating-Current Series Enclosed-Arc Lamps. Enclosed arcs are now very often operated in series by constant current on alternating-current systems, i. e., the alternating current through the series of lamps is maintained at a constant value. The lamps used do not differ essentially from those for constant direct-current circuits, except that all magnet cores and armatures are laminated to prevent heating due to eddy currents, and the mechanism is designed so as to avoid disagreeable humming. The methods for supplying current to series alternating-current lamps and the arrangements for maintaining the current at constant value will be taken up when the subject of station apparatus is considered.

65. Current.—Series enclosed-arc lamps are ordinarily operated at about 6.6 amperes, and the voltage per lamp is from 70 to 78 volts, depending on the length of arc for which the lamp is adjusted. These lamps have also been built for a current as large as 8 amperes, with a correspondingly lower voltage, but the values given above are the ones commonly met with.

66. Remarks on Enclosed-Arc Lamp Construction. The mechanism of an enclosed-arc lamp generally contains the same essential features as the corresponding open arc, but in most cases the arrangement is simpler. The open arc must be fed frequently, because the carbons burn at a comparatively rapid rate and the clutch or other feeding mechanism must be accurately adjusted and kept in good condition if the lamp is to burn steadily. For this reason, the upper carbon of an open-arc lamp is attached to a carbon rod on which the clutch operates, and which is, or should be, kept in a clean, polished condition. The current is generally carried to the top carbon by means of a copper brush pressing against the rod. In the enclosed-arc lamp the operation of feeding takes place at comparatively long intervals, and the feeding mechanism does not need to be so delicately adjusted. It is, therefore, a common practice to have the clutch operate directly on the carbon and to dispense entirely with the carbon rod. Such lamps are spoken of as having a **carbon feed.**

The doing away with the carbon rod makes the construction simpler and cheaper, besides allowing the lamp to be made shorter than is usual where a carbon rod is used. Short lamps are desirable for inside work, as they look better, especially in places where headroom is limited. Some enclosed-arc lamps, however—the Wood lamp, for example—use the carbon rod. The omission of the carbon rod, while it simplifies the construction in some respects, is not without its drawbacks. It is not as easy to conduct the current into the carbon without interfering with its free movement, and the contact rings or other devices on many of these lamps give trouble. To get around this, some makers use a flexible cable or chain attached directly to the carbon holder; but flexible cables are also apt to give trouble unless they are looked after and kept in good condition.

On account of the long arc common to enclosed-arc lamps, their mechanism must be arranged so that it will have a long pick-up; i. e., when the lamp starts up the mechanism must be such as to pull the carbons a considerable distance apart. In the case of series lamps, an automatic cut-out must, of course, be provided.

67. In taking up the subject of enclosed-arc lamps, we will confine our attention to two or three typical examples that will serve to bring out the essential points relating to their construction and operation. The number of different makes of enclosed-arc lamp is very large, but they differ from each other principally in details of construction. The principles of operation are about the same in all of them, and the following are not selected because they operate any better than several others, but because they will serve to bring out the points aimed at.

68. Series Enclosed-Arc Lamps for Constant Direct Current.—Fig. 33 shows the general arrangement of the mechanism of a series enclosed-arc lamp made by the General Electric Company and designed for use on constant direct-current circuits. This figure shows the arrangement of the essential parts of the mechanism in order to bring out its method of operation, and Fig. 34 shows the general scheme of connections. In some respects, it resembles the Brush series open-arc lamp previously described. It is of the differential type, and is provided with two series coils *M* and two shunt coils *S*. In Fig. 33, only one of each of these coils is seen, as they are in line with each other. A tube *T* holds the upper and lower parts of the lamp together, and in it the carbon holder *H*, carrying the upper carbon *U*, is free to slide up and down. Current is carried to *U* by means of the flexible asbestos-covered cable *C*, which follows the carbon up and down through a slot cut in one side of the tube. The rocker is made up of two levers, *a* hinged at *a'* and *b* hinged at *b'*. These levers are connected by a spring *c* that will allow one armature to move independently of the other to a slight extent and make the action of the lamp steadier. The iron armatures *d* and *e* are carried by these levers, as shown, and when one moves up the other

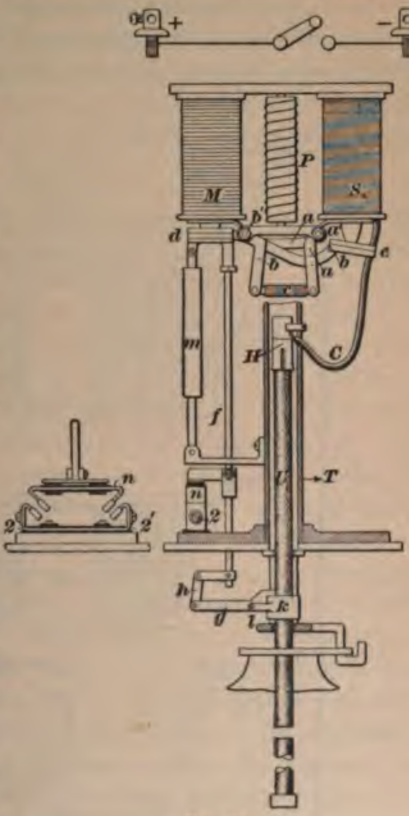


FIG. 33.

moves down a corresponding amount. Each armature is provided with two holes, through which the conical pole pieces project when the armature is pulled up. The clutch rod *f* is attached to but insulated from the rocker *a*, and is fastened to the clutch *g* through the small link *h*. The rocker and clutch are shown in about the position they occupy after the lamp has just been started. When the lamp is out of circuit, armature *c* is up at its farthest position and armature *d* is down, the clutch ring *k* rests on the tripping table *l* and the carbons are together. A dashpot *m* is provided to steady the action of the lamp, and the cutout preserves the continuity of the circuit and protects the

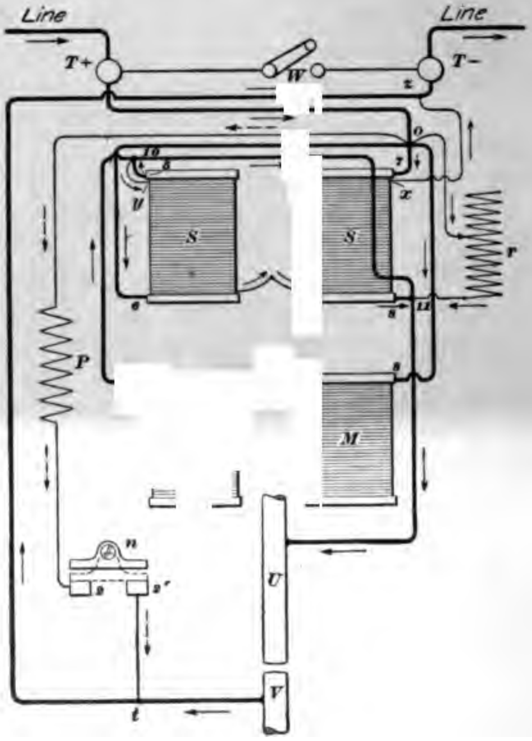


FIG. 34.

shunt coils in case the carbons should fail to feed or should be broken. The cut-out consists of a crosspiece *n* carried by the clutch rod, but insulated from it, and provided with silver contact pieces. Below the crosspiece, two insulated contacts *2*, *2'*, also tipped with silver, are arranged. When the current in the shunt coils becomes excessive, the armature *c* is pulled up so far that *n* is brought into contact with *2*, *2'* and the lamp is cut out, unless the carbons feed down so as to enable it to start again.

69. By referring to the diagram, Fig. 34, the action of the lamp under normal conditions will be understood. The coils *M*, *M* are provided with a single winding of heavy wire that is capable of carrying the current used on the circuit. The coils *M*, *M* are here shown below *S*, *S* for the sake of clearness, but it will be understood that the two pairs are opposite each other, as shown in Fig. 33, and oppose each other by pulling on the armatures of the rocker. The bulk of the winding on coils *S*, *S* consists of a large number of turns of fine wire. This winding is in shunt with the arc, and its terminals are shown at *x*, *y*. In addition to this shunt winding, each coil *S*, *S* is provided with a few turns of heavy wire, the terminals of which are shown at *5*, *6*, 7, and *8*. These coils are in parallel with the main coils *M*, *M* and are known as compensating coils; *r* is an adjustable resistance in shunt with the series coils to enable the current passing through them to be adjusted. The resistance *P* is connected in series with the cut-out, as shown, and is used to enable the lamp to start up, as previously explained in connection with the Brush and Wood lamps. The switch *W* is provided to short-circuit the lamp when it is desired to cut it out of circuit.

70. When the lamp is not burning, the weight of the moving parts causes the armature *c* to come up against *S*, Fig. 33, the carbons are in contact, the clutch *k* rests on the tripping table *l*, and *n* is in contact with *2*, *2'*. As soon as the current is turned on, part of it takes the path *T*+-*o*-*P*-*2*-*n*-*2'*-*t*-*T*, Fig. 34. On account of the resistance *P*, however, the greater part will take the path $T+-0-8-9-10-11-U-V-t-T$, because the carbons are, at the start, in contact. This will energize the series coils M, M, and the armature d, Fig. 33, will be pulled up, thus cutting off the current through the resistance P by raising n off 2, $2'$. A certain amount of current also passes through the coarse-wire coils wound under S, S from 0 to 11 and through the paths $0-6-10-11$ and $0-7-11$, but the coils M, M are so much more strongly magnetized than S, S that the armature d is pulled up against the attraction exerted on e, Fig. 33. As soon as [illegible] re d is drawn up by the series magnets, the carbons [illegible] eparated and current then flows through the s [illegible] g by the path $10-y-S-S-x-s-T$; the shunt co [illegible] ctically connected across the terminals of the [illegible] as the carbons are pulled apart, the current thr [illegible] coils increases. As armature d is pulled up, [illegible] he pull on e is increased and a point is soon rea [illegible] re the two pulls are balanced. As the carbons [illegible] ay, e is raised still more, the carbons are brought [illegible] and clutch k moves down with the carbon until finally k rests on the table l, Fig. 33, and any further downward movement of the rod f lowers g and releases the clutch. This allows the lamp to feed and armature e then lowers to its normal position. If the carbons should stick and the arc become abnormally long, e would be pulled up far enough to bring n in contact with 2, $2'$. The current would then take the path through the resistance P and the series coils would be cut out. The shunt coils would, however, still be subjected to a small E. M. F., due to the drop through P, and the armature e would be firmly held in place. If, in the meantime, the carbon should become released and slip down, the current would take the path through the series coils and carbons in preference to that through the resistance P. This would bring the series coils into action and cause the lamp to start up.

71. Compensation for Heating.—In order to keep the voltage at the arc of a constant-current series lamp at a uniform value, it is necessary to have some automatic device to compensate for the increase in resistance of the shunt coils due to the heating of the lamp. The shunt coils have a considerably higher resistance after the lamp has been running an hour or two than when the lamp is first started. Now, the voltage across the shunt coils is equal to the voltage across the arc, and if the arc is to be maintained at the same length, some means must be provided for keeping the pull exerted by the shunt coils uniform. A number of methods have been adopted to accomplish this. One common method for differential lamps is to shunt the series coils by means of a resistance having a low temperature coefficient, i. e., a resistance that increases but very little with an increase in temperature. When the coils become heated, the pull of the shunt coil decreases, but the pull of the series coils also decreases, because they become heated and, being of copper, increase considerably in resistance, so that more of the current passes through the shunt having a low-temperature coefficient. Fig. 35 is a simplified diagram of connections for the lamp shown in Fig. 33. *M*, *M* are the main series coils and *S'*, *S'* the compensating coils that constitute the shunt to *M*, *M* and take an increasing amount of current from *M*, *M* as these series coils become heated. The result is, that although the pull of *S*, *S* decreases as the

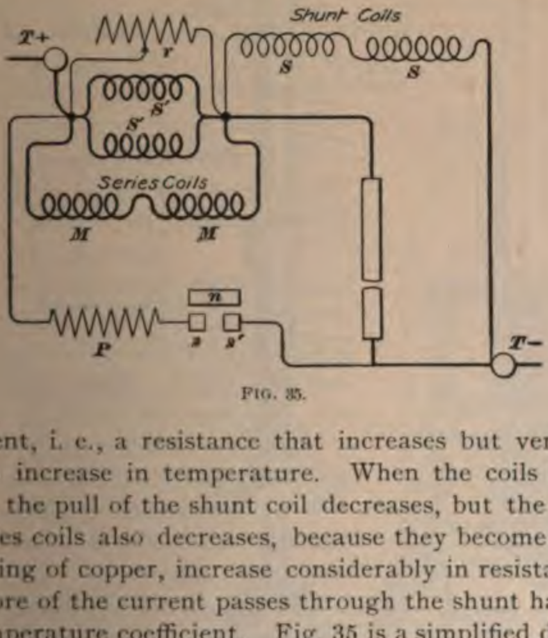


FIG. 35.

lamp warms up, the balance between the shunt and series is maintained and the voltage at the arc kept at its proper value. In some cases the lamp is provided with a thermostat that closes a circuit and cuts out part of the shunt coil,

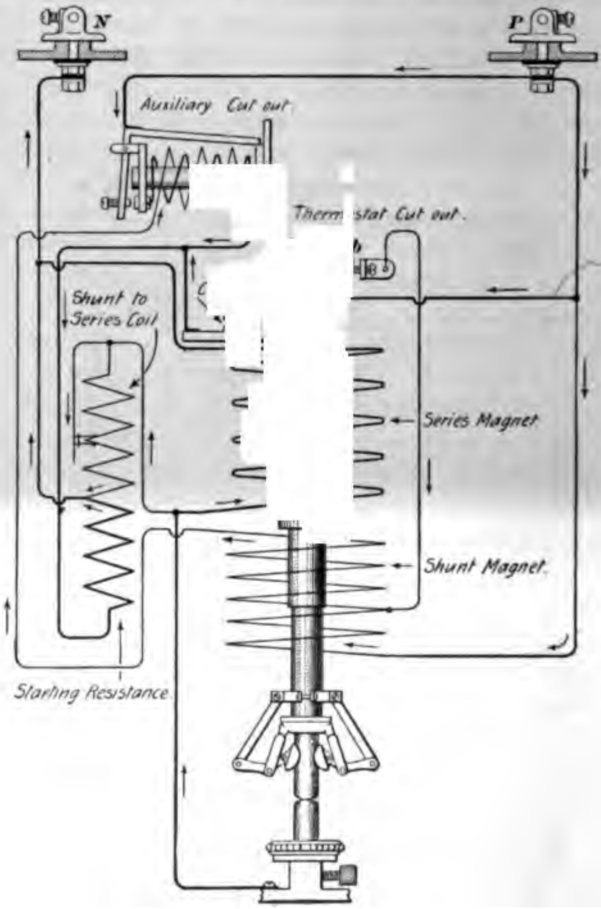


FIG. 36.

thus decreasing its resistance, when the lamp becomes hot. Fig. 36 shows the connections of the Gilbert enclosed-arc lamp for constant-current circuits. This is a differential lamp using a thermostat to cut out part of the shunt coil when the lamp becomes hot. The thermostat consists simply of a curved strip of metal attached to the frame of the lamp. When the frame becomes heated, the expansion of the strip *a* brings it into contact with *b*, thus cutting out part of the shunt coil. In this lamp, the shunt and series coils are arranged one directly above the other and act on a movable core that operates the clutch. From what has been said regarding the lamps previously described, the student should be able to trace out the circuits in Fig. 36. The adjustable resistance, like that of all the other lamps described, is in parallel with the series coil and is used to adjust the length and, hence, the voltage of the arc.

72. Fig. 37 shows the general appearance of a Wood series enclosed-arc lamp. This lamp is provided with a regular carbon rod, instead of a carbon feed, and therefore must be provided with a chimney *A*. This figure shows the general arrangement of the enclosing globe with its gas cap.

In enclosed-arc lamps of the carbon-feed type there is always a considerable length of the upper carbon that cannot be fed down. This, however, does not involve any waste, as the length of upper carbon left over is sufficient for use as a lower carbon when the lamp is retrimmed.

Series constant-current enclosed-arc lamps of the types just described usually operate at 6.6 amperes with a voltage of about 72 across the arc. The lamp shown in Fig. 35 uses $\frac{1}{2}$-inch solid carbons and burns from 100 to 120 hours without retrimming. In alternating-current lamps the top carbon is cored and the bottom solid.

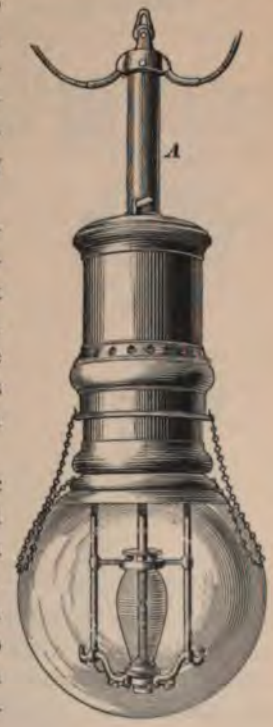


FIG. 37.

73. Series Alternating-Current Enclosed-Arc Lamps. These need no special description, as their principle of operation is exactly the same as the direct-current lamp. They are nearly always of the differential type, and the main difference is in the few constructional details referred to in previous articles.

CONSTANT-POTENTIAL ARC LAMPS.

74. As soon as the [illegible] l arc was introduced, it almost immediately re[illegible] e open arc for constant-p[illegible] work. We will therefore [illegible] r attention, in considering [illegible] otential lamps, to the en-[illegible] e. The great advantages [illegible] closed-arc lamp for this [illegible] he high voltage and small [illegible] quired, which enables them t[illegible] erated singly across the mains, also the soft, steady light and the long life of the carbons.

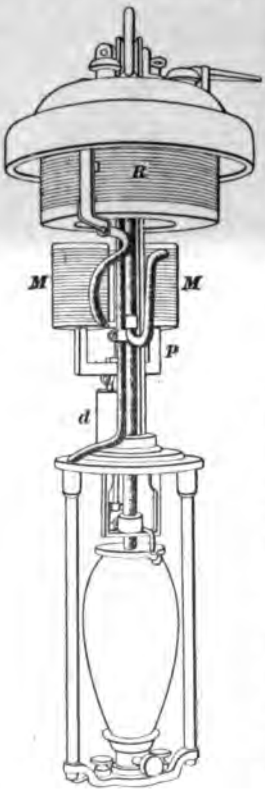


FIG. 38.

75. The mechanism of the constant-potential enclosed-arc lamp is, as a rule, very simple. The feeding is controlled by a magnet connected in series and there is no need of a cut-out. The lamp should, however, be connected to the circuit through fuses, so that it will at once be disconnected in case of a short circuit anywhere in the mechanism. The series-controlling magnet is usually arranged so that it attracts a core or plunger against the action of a spring or, more commonly, against the action of gravity.

6. Direct-Current Constant-Potential Enclosed-Arc nps.—Fig. 38 shows a lamp that is similar in many ›ects to the constant-current lamp previously described. : general features, such as the framework, clutch, method :arrying current into the upper carbon, etc., are the ıe in both. The magnets *M* are in series and arranged

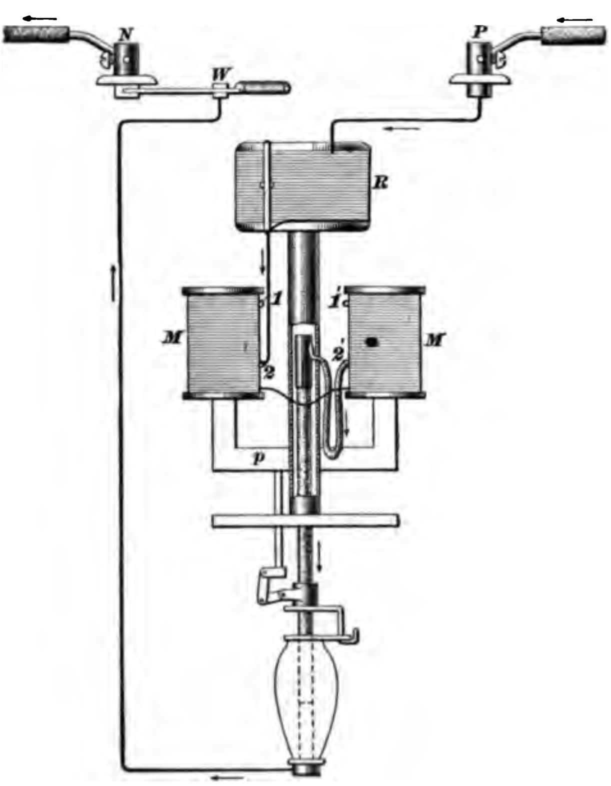


FIG. 39.

ıs to pull up the plunger *p*. This plunger operates the .ch rod and its movements are dampened by means of dashpot *d*. *R* is the resistance wound on an insulating nder and connected in series to take up the excess .age and steady the action of the lamp. Fig. 39 shows general arrangement of the mechanism and gives the connections, which are very simple. Notice that the switch *W* cuts out the lamp by opening the circuit through it, not by short-circuiting it, as in the case of constant-current lamps. Current enters at *P* and flows through the resistance and series coils to the upper carbon, thence to the lower carbon to *N*. This causes the core to be pulled up and the carbons to be separated. As the [illegible] away, the current becomes we[illegible] *p* gradually lowers until the [illegible] is released and the lamp feeds. [illegible] resistance is provided with a sli[illegible]ntact, so that the lamp may [illegible] for pressures varying from [illegible] volts. The series coils are [illegible]th two connections *1*, *1'* and [illegible] at the lamp may be made to o[illegible] at 4½ to 5 amperes or 3½ to 4 amperes. When the larger current is used, the connections are as shown in the figure, because fewer turns are then needed to operate the plunger. Solid carbons ½ inch in diameter are generally used, and the voltage at the arc is about 80, leaving 20 to 40 volts to be taken up in the resistance. With ½-inch carbons, the lamp will burn 130 to 150 hours without retrimming.

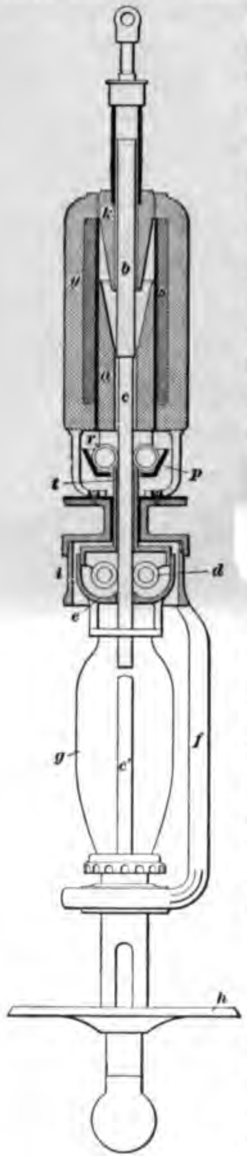


FIG. 40.

77. Fig. 40 shows another form of constant-potential enclosed-arc lamp, of which there are a large number in use. This lamp is very heavily constructed, and has a rather peculiar clutch and contact arrangement for carrying the current into the upper carbon.

There is but one solenoid *s*, which is connected in series with the carbons and has a compact magnetic circuit through the yoke *y*, the conical core *k*, and the armature *a*. The armature carries at its lower end a pan *p* containing four clutch rings *r* that fall by gravity and grip the carbon *c* by wedging between the carbon and the inclined side of the pan. As the carbon falls by reason of the consumption at the arc or through the current being interrupted, the pan is lowered until the rings are caught by the tube *t*, which is supported by the frame of the lamp. This action releases the carbon, which then falls towards the lower carbon *c'*, but the consequent reduction of resistance causes a large current to flow through the coil *s*, which draws up the armature, and with it the carbon *c*, to the normal height. Regulation is, then, effected by the differential action of a series coil and gravity, for the moving system is designed to have considerable weight. The upper carbon is held in a sheath *b*, which permits the using of shorter carbons than would otherwise be necessary. The sheath will readily pass between the clutch rings and through the tube *t*. The current is conducted to the carbon by means of sixteen contact rings *d*, enclosed within a box *e* and making a flexible contact with the carbon. The inner globe *g* surrounds the carbons and is supported by the arm or yoke *f*. The outer globe fits over the plate *h* at the bottom and is secured at the top by a circular nut at *i*, the joint being packed by means of asbestos gaskets. The space immediately above *h* and below the inner globe is intended for the rheostat. In the later styles of this lamp the rheostat is placed in a small metal case at the top of the lamp.

78. Alternating-Current Constant-Potential Enclosed-Arc Lamps.—Fig. 41 shows the arrangement of an alternating-current constant-potential lamp. The general appearance of the lamp is almost exactly the same as that shown in Fig. 38. The principal distinguishing feature of the alternating-current lamp is the use of the reactance, or choke, coil *L* in place of the resistance. This consists of a laminated iron core *a* on which coils *b* are wound. These coils are connected in series and the ends *1*, *2*, *3*, *4*, etc.

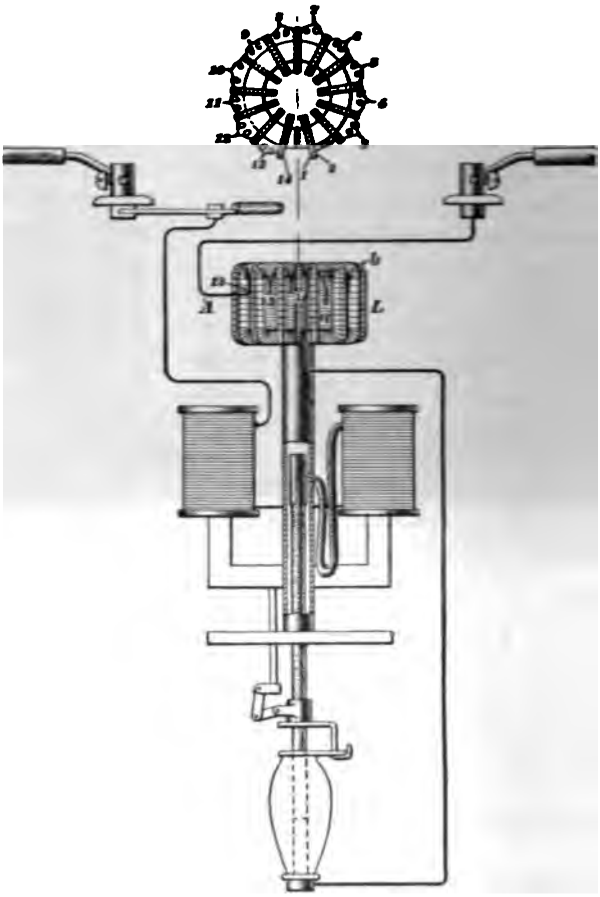


FIG. 41.

left so that the wire *A* may be connected at different points. This allows the lamp to be adjusted for a consid-
ble range of voltage and frequency. The reactance
ounter E. M. F., and thus introduces an

apparent resistance into the circuit which counterbalances the excess voltage and makes the lamp stable in its operation. The reactance coil is more economical than a resistance, but it and the series magnets introduce self-induction into the circuit and thus make the lamp have a power factor less than 1. A load of alternating-current arc lamps is always inductive, and this has in some instances been used as an argument against them. They are, however, well adapted for stations already equipped with alternating-current apparatus and where it is desired to operate arc lamps with the least expense for additional equipment. The frequency should not be below 60 cycles per second for satisfactory operation.

The lamp just described will operate anywhere from 60 to 140 cycles. It takes about 72 volts at the arc and burns from 80 to 100 hours. The upper carbon is cored and the lower carbon solid.

79. Connections for Constant-Potential Lamps.—Fig. 21 shows constant-potential lamps connected across a 110-volt circuit. Each lamp should be connected to the mains through any good style of double-pole fuse block. In most cases, it is also desirable to equip each lamp with a switch in addition to the switch that is on the lamp itself, as this switch is not always easily accessible. Where separate switches are used, they should be double-pole if the lamp takes more than 3 amperes. In connecting up constant-potential lamps, the branch wires should be proportioned for at least 50 per cent. more current than the lamp takes, because at starting the current may be much in excess of the normal. Fig. 22 shows constant-potential alternating-current lamps connected on a 104-volt alternating-current circuit. The connections are practically the same as those shown for the direct-current circuit, except that the lamps are here fed from the secondary of the transformer. Enclosed arcs are also made for operation on 220-volt circuits, but these high-voltage lamps are not as efficient as those for lower voltage.

Enclosed arcs are sometimes operated two in series on 220-volt mains, or four or five in series on 500-volt mains where it is desired to operate a few arc lamps from a power circuit. This method of operation is, however, not as satisfactory as when each lamp is independent and it is only adopted in case of necessity.

CARE AND AI T OF ARC LAMPS.

80. General Remark an arc lamp is kept clean,
and if the current and which it is operated are
maintained at the valı hich it is designed, it will
give little trouble. Thi , of course, that the lamp
is substantially made. s seems to be the principal
object in some lamps, he first cost of such is low,
the bill for repairs they are much the more
expensive in the lc older styles of open-arc
series lamps were us y built and, as a rule, gave
good service. We will first consider some points in connection with lamps of this class.

81. Trimming.—Most open-arc series lamps are provided with a carbon rod on which the clutch operates. If this rod is dirty or greasy, the clutch will not work properly and the lamp will give poor service. When trimming the lamp, the rods should never be pushed up when they are in a dirty condition.

Dirt on the rod is apt to cause pitting, due to the burning action of the current where it passes into the rod from the contact spring or bushing. If the rods are at all dirty, they should be rubbed down with a piece of worn crocus cloth. When trimming the lamp, care should be taken to see that the carbons are of the proper length. Lack of care in this particular is often responsible for burned carbon rods and carbon holders. The carbons should be placed so that they are vertically in line with each other, and the upper carbon must have enough vertical play to allow the lamp to pick up its arc.

82. Adjustments.—The principal points to look out for in adjusting an arc lamp are to see that the arc burns at the proper length and that the carbon is fed down smoothly without any hissing or flickering. For an ordinary 1,200 nominal candlepower open-arc lamp, the arc should be about $\frac{3}{64}$ inch in length; for a 2,000 candlepower, from $\frac{1}{16}$ inch to $\frac{3}{32}$ inch. The exact length will depend somewhat on the quality of the carbons. If the arc is too short, it is liable to hiss, or if the current is too large, hissing is apt to result. An arc that is too long will flame badly and the lamp will take more voltage than it should. Poor quality of carbons will also cause flaming or hissing. The length of arc and the feeding point may be regulated by proper adjustment of the clutch. Directions for adjusting each particular make of lamp are furnished by the makers, but as a rule such adjustments are easily learned by an inspection of the lamp itself. In some cases the clutch and rod may become so worn that they must be replaced before a satisfactory operation can be obtained.

A good method to follow in adjusting lamps is to connect an ammeter in series and a voltmeter across the terminals of the lamp. The first thing to look out for is to see that the dynamo is maintaining the proper current in the circuit. If it is not doing so, the regulator on the dynamo should be adjusted until it does. The lamp should be hung in some place where it will not be exposed to drafts of air, because such drafts may cause the arc to hiss or flame even if it is properly adjusted. A rack should be provided for supporting the lamps at such a height that the mechanism may be easily inspected. By watching the fluctuations of the voltmeter as the lamp burns, a good idea may be formed as to the smoothness with which the lamp feeds. A recording voltmeter is very convenient for this work, as the lamp may be left to itself for some time, and the voltmeter will draw a chart indicating the variations in voltage during the gas caps of enclosed-arc lamps and also to the joint between the globe and the bottom carbon holder. If there is too much air admitted, the carbons will be consumed rapidly. If the globes are too tight, very little air will be admitted and the unconsumed carbon will be deposited on the globe.

86. Since most enclosed-arc lamps have a carbon feed, it is necessary to see that the carbons are smooth, because rough spots will interfere with the operation of the clutch. If necessary, rough spo l be smoothed down with sandpaper. Constant-pot mps have no cut-out to give trouble, but they have a re ce coil that fully counterbalances the cut-out in this . If the carbons stick and fail to feed, the lamp goe t if the lamp does not pick up properly, the carbons in contact, the resistance offered by the arc wi nd a current much larger than the normal will e fusible cut-out in series with the lamp does e resistance will be very liable to overheat and b There is also danger of the insulation on the series controlling magnet being damaged, It is a common occurrence to find constant-potential lamps that have been designed and adjusted for 104 to 110 volts running on circuits where the voltage is as high as 125 or 130. Of course, under these circumstances the lamp takes a current larger than it should, and it must not be forgotten that the heating effect in the resistance coil and other parts of the lamp runs up as the square of the current. A comparatively slight increase in the current will, therefore, result in quite a large increase in the heat developed, and this in the course of time is sure to result injuriously. An abnormal current is also liable to melt the enclosing globe. Of course, many of the burn-outs on these lamps may be traced to faulty design or construction, but at the same time it is quite true that many good lamps give trouble either because the voltage is too high or because the lamp has not been properly adjusted to suit the voltage on which it is to operate.

LINE WORK FOR ARC LIGHTING.

SERIES SYSTEMS.

87. Size of Wire.—Since most outside lighting work is done on the series system, and the current being usually not greater than 9.6 amperes, the line wire does not need to be large. Generally, such lines are of No. 6 B. & S. double- or triple-braided weather-proof wire. Triple-braid wire of this size weighs about 585 pounds per mile; double-braid wire weighs about 510 pounds. Its resistance per mile is approximately 2.08 to 2.12 ohms. Sometimes No. 8 wire is used for arc lines, but while it is large enough to carry the current, it does not make as substantial a job as the No. 6. The difference in first cost between the two sizes is not great and, as a general rule, it will pay to put up the larger wire, especially in localities where sleet storms are common.

88. Since the current is small, series arc lines may be run long distances without having an excessive loss. For example, with a 9.6-ampere current, the drop per mile of wire would be about $2.08 \times 9.6 = 19.97$ volts. Series arc circuits often extend for miles, but the extension of the line simply cuts down the pressure available for the lamps, so that a given dynamo is not capable of operating quite as many lamps on a long circuit as on a short one.

89. Laying Out Arc Circuits.—There is, generally, not a great deal of choice as to the laying out of an arc circuit for street lighting, as it is determined almost altogether by the location of the lamps. At the same time, wire and labor can often be saved by laying out a plan of the streets to be lighted and then arranging the circuits so that the line will pass through one lamp after another with as little doubling back on itself as possible.

When laying out the line, it is a good plan, where possible, to connect the terminals of a loop in the circuit to a switch so that, in case of trouble, the loop may be short-circuited blocks are long, they are also placed in the middle of the block. The older method was to use a comparatively small number of lamps hung high above the street, but it is now considered better practice to hang the lamps lower and to use more of them if necessary. This is especially the case when the streets are shaded by trees. Where the space to be illumi- d is open, the lamps may ung fairly high, say 30 to et above the ground; but when the streets are at all shaded, a height of 20 to 25 feet is to be preferred.

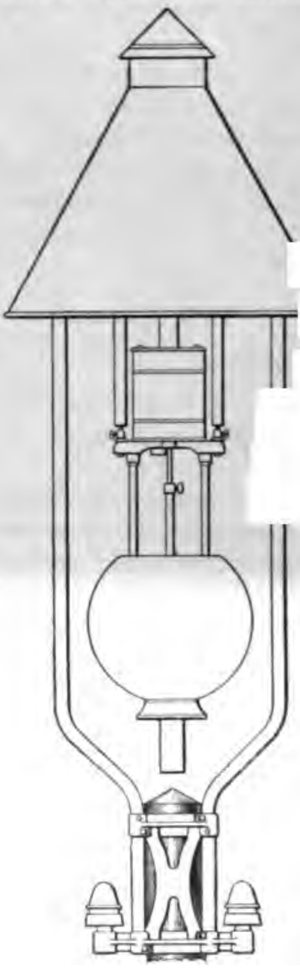


FIG. 43.

FIG. 44.

93. Methods of Hanging Lamps.—There are, in general, three methods of hanging lamps: (*a*) By mounting on pole tops; (*b*) by suspending from mast arms or pole fixtures projecting from a side pole; (*c*) by suspending from the middle of a span wire so that they will hang over the middle of the street.

When the lamps are mounted on **pole tops,** they are fixed permanently, no provision being made for lowering them when they are trimmed. The pole must, therefore, be provided with pole steps, so that the trimmer may climb up to the lamp. This method of mounting makes the work of trimming hard, and it is, therefore, not used nearly so much as other methods, which allow the lamp to be lowered for trimming. Fig. 43 shows a lamp with the pole-top mounting. It is necessary to provide a hood to protect the top of the lamp. With the older styles of lamp, these hoods were large enough to accommodate a **hanger board,** from which the lamp was suspended. In the newer lamps, a much smaller hood is sufficient. This method has a few advantages, among which are the absence of rope and pulleys, also the line wires when once connected up are not moved, as they are every time a lamp is raised or lowered. The raising and lowering of lamps is a frequent source of breaks in the line wire due to the slight bending and unbending that the wire is subjected to. These advantages are, however, more than offset by the difficulty of trimming if the lamps are mounted high above the street. Fig. 44 shows a more ornamental style of pole-top mounting. In this case, the lamp is only about 20 feet above the street, and as it is used with enclosed arcs, which are trimmed about once in a week or ten days, the climbing up to the lamp is not as much of an objection as when open arcs, requiring daily trimming, are used.

94. Fig. 45 illustrates a typical mast-arm suspension. The general arrangement will at once be seen from the figure. The lamp is raised and lowered by means of a rope and pulleys, and is provided with a small hood *b* to protect the top from the weather. The lamp is suspended from the rope by the intervening cross-arm *a* and insulator *b*. A cross-arm and insulator of this kind should be provided in order to secure good insulation between

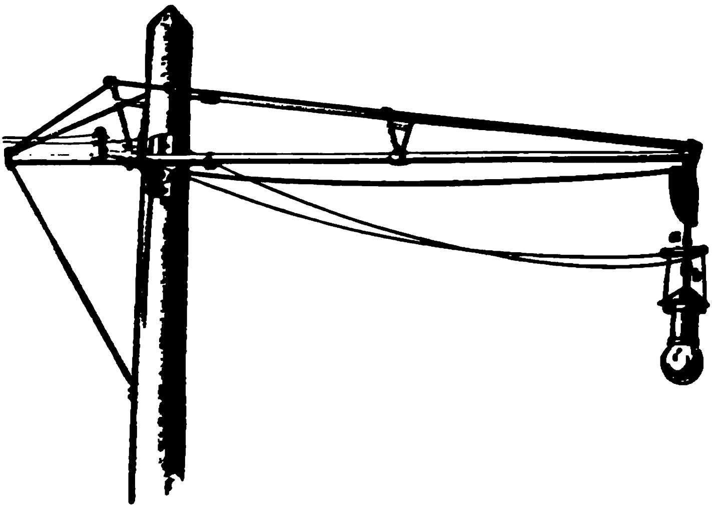


FIG. 45.

the lamp and the pole fixture and also to keep the line wires spread apart.

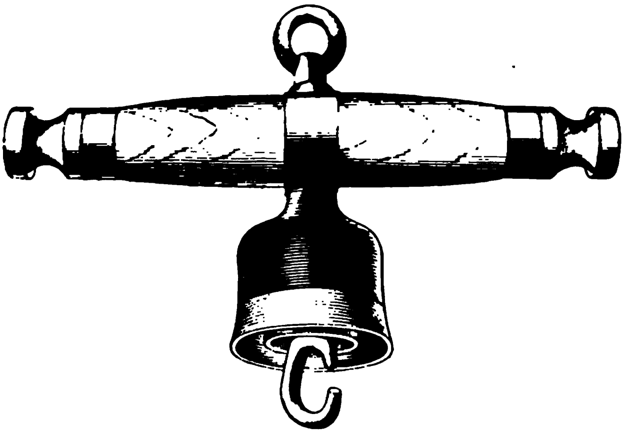


FIG. 46.

Fig. 46 gives a view of a Cutter insulating cross-arm. Since the introduction of high-voltage enclosed arcs and the operation of a large number of lamps per circuit, it is essential that each lamp be provided with a suspension that will give high insulation. The old-style, plain, wooden crosspiece with a porcelain knob at each end is hardly sufficient.

Some styles of mast arm are pivoted at the pole and are counterbalanced so that the arm may be swung down for trimming.

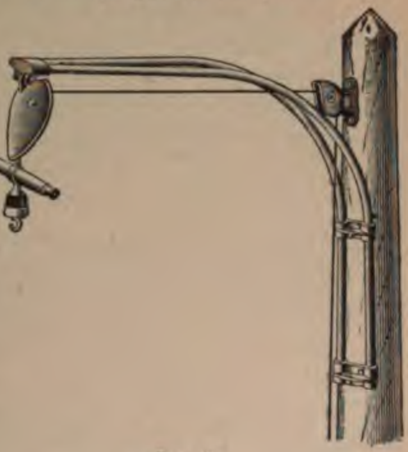


FIG. 47.

Fig. 47 shows a Cutter pole fixture of small size that has been used considerably for street lighting with enclosed arcs. It supports the lamp about 3 feet from the pole.

95. The span-wire method of suspension is illustrated in Fig. 48. It is the best form to use when it is desired to bring the lamp over the center of the street. A pulley is placed at the center and another on the side pole and the

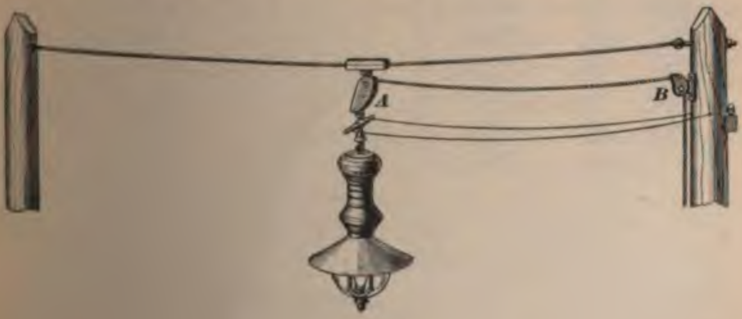


FIG. 48.

poles are usually set at diagonally opposite corners of the street intersection. The span or suspension wire is usually of $\frac{5}{16}$-inch or $\frac{3}{8}$-inch galvanized steel and the side poles about 30 to 35 feet high with a 6-inch top. This method of suspension, of course, involves the use of two poles and for this reason the mast-arm suspension is often preferred. The chances are that for lighting a given town or city a combination of the three may be desirable, the style of suspension being chosen that is best adapted for the particular location of the light.

96. Arc-Lamp P alleys used for suspending
arc lamps have receiv t deal of attention at the
hands of those especia ed in arc-lamp specialties.
The ordinary style of t well adapted for this kind
of work. An arc-lar hould always be provided
with a hood to preven clogged by sleet. It is also
desirable that the ich the lamp is hung be of
such a design tha e lamp from dropping in
case the rope b s unfastened in any way.
In Fig. 48, a lamp-suppo ley is indicated at *A* and a swivel-pole pulley at *B*. Both are of the sleet-proof kind. A number of different types of lamp-supporting pulleys are now manufactured. In most of them either a catch or projections are arranged inside the pulley casing so as to hold the lamp when it is raised and relieve the rope of all strain. When the lamp is to be lowered, it is first pulled up a little. This unlocks the pulley and allows the lamp to be lowered. The use of self-locking pulleys also helps to make the operation of trimming more rapid.

Arc-lamp pulleys have also been brought out that contain a switch that cuts off the lamp entirely from the circuit when it is lowered. This allows the lamp to be lowered without lowering the wires running to it, and also makes it perfectly safe to work on. These pulleys are, however, somewhat complicated.

97. Rope.—The rope used for raising and lowering the lamps is an important item on a large system and it should be carefully selected. Practice varies greatly as to the kind of rope used. Formerly, manila rope was used almost exclusively, but the tendency is now towards a solid braided cotton rope or a flexible wire rope. When cotton is used for this purpose, it is provided with a wax finish that keeps the rain from soaking into and rotting it. This rope is usually $\frac{3}{8}$ inch in diameter, though $\frac{1}{2}$ inch is sometimes used with heavy lamps. If wire rope is used, it is usually the so-called tinned "sash cord," which is a rope made up of a hemp center surrounded by tinned steel wire. When a metal rope is used, an insulator should be cut into it at a point just outside the pole pulley in order to insulate the trimmer's end of it. When the lamps are very heavy, a small windlass is frequently used to hoist them.

98. It was formerly the practice to coil up enough surplus rope on the pole at each lamp to allow the lamp to be lowered to the ground. It is now customary to end the rope in such a way that another rope may be hooked on to it and the lamp lowered. This extra rope, known as a **trimmer's rope,** is from 20 to 30 feet long and is provided with a snap hook at one end and a number of rings near the other, the latter being spaced so as to suit the varying heights at which the lamps may be hung. The end of the rope on the pole may be fastened by means of special pole padlocks, made for the purpose, but in many cases it is simply slipped over a pin, as shown in Fig. 49. The use of the lock is, however, safer, as it prevents the lights from being tampered with.

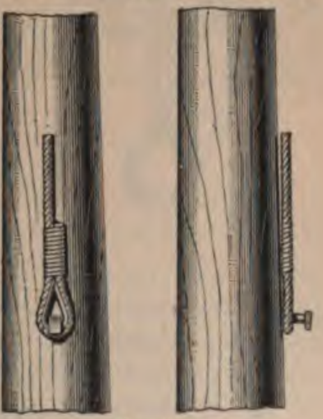


FIG. 49.

99. Cut-Out Switches.—The rules of the Fire Underwriters require that wherever constant-current arc wires enter a building, an approved double-contact service switch shall be installed, so that the current may be cut off at any time. These switches must be substantially made, must be mounted on incombustible bases, and must be placed where they may be easily reached by policemen and firemen. There are many different types of these cut-out switches, but they should all have good contacts and be quick in action. The switch must also show clearly whether the current is on or off.

Fig. 50 shows the working parts of the Wood arc cut-out, a style that has been extensively used and which will serve to illustrate the operation of cut-out switches in general. The parts here shown are mounted in a waterproof cast-iron box with an opening past which an indicator moves to show when the current is on or off.

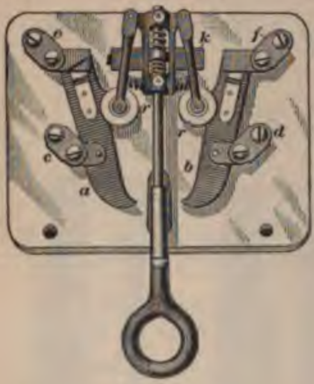


FIG. 50.

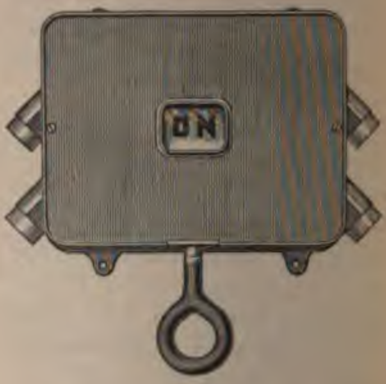


FIG. 51.

Fig. 51 shows the external appearance of the switch. Two blades *a*, *b*, Fig. 50, are attached to the line terminals *c*, *d*, as shown. The house terminals are connected to the posts *e*, *f*. When the handle is pushed up, the porcelain rollers *r*, *r* press the blades into the clips on terminals *e*, *f* and thus connect the line with the lamps. When the lever is pulled down, the rollers bear on the lower part of the blades, causing them to leave the clips on the posts *e*, *f* and swing over so as to rest on the casting *k*, thus cutting out the lamps and allowing the current to flow directly across from one blade to the other and disconnecting the house wires entirely from the line. The springs shown in the figure make the action quick and positive.

100. Cut-Outs on Arc Lamps.—Nearly all arc lamps are provided with a simple short-circuiting switch by means of which the lamp may be cut out. This switch does not, however, disconnect the lamp entirely from the circuit, and it is always dangerous to work on a lamp under such circumstances when standing on the ground, because there is liable to be a ground on some part of the line and thus establish a path for the current through the person working on the lamp. Since the introduction of constant-current circuits operating a large number of lights, the danger from shock has materially increased, and to get around this, lamps are now frequently equipped with individual cut-out switches that are separate from the lamp and that will cut out the lamp and disconnect it entirely from the circuit. Fig. 52 shows a series arc lamp equipped with a separate cut-out switch of this kind.

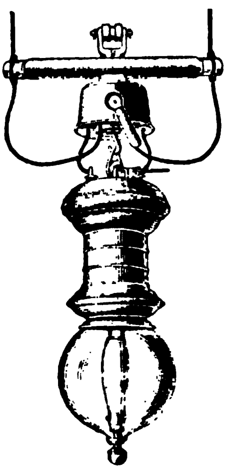


FIG. 52

101. Looping in Lamps on Series Circuits.—When a lamp is looped in on a series circuit out of doors, it is not necessary to provide a cut-out switch at the point where it is cut into the line, though, as mentioned in the previous article, switches are sometimes placed at

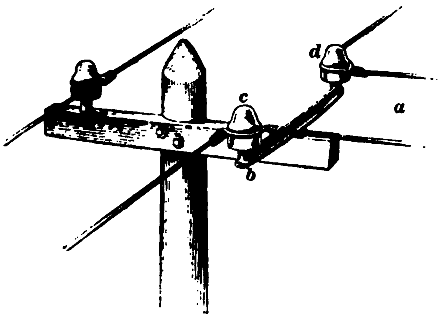


FIG. 53.

the lamp itself. Fig. 53 shows one method of looping in on a series circuit. An arm *b*, provided with insulators *c*, *d*, is mounted as shown. The loop *a* runs to the lamp or, in case the circuit is carried into a building, runs to the cut-out. Fig. 54 shows another method, which is not quite so neat, but does not call for the use of a special bracket. The break in the circuit is made by using two ordinary porcelain insulators *m*, *n* and a double-petticoat glass insulator *i*. When a circuit is to be looped in between poles, the break may be made by using

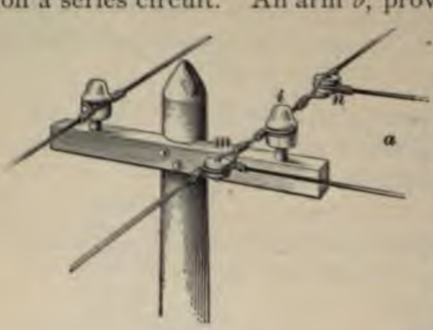


FIG. 54.

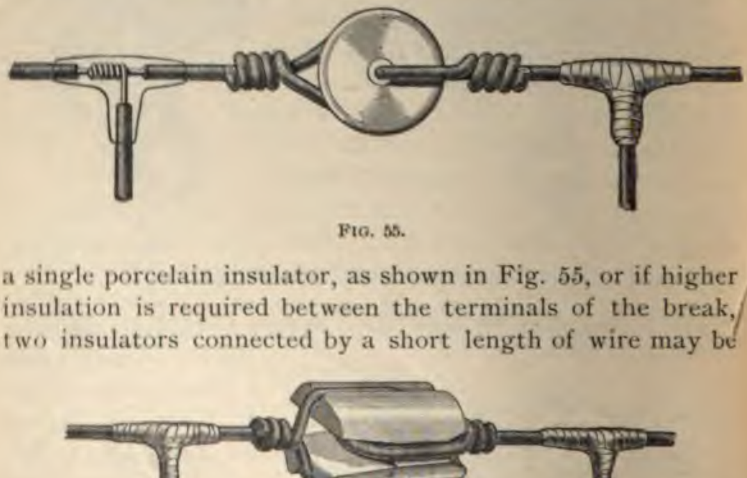


FIG. 55.

a single porcelain insulator, as shown in Fig. 55, or if higher insulation is required between the terminals of the break, two insulators connected by a short length of wire may be

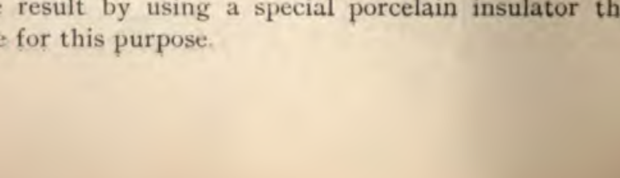
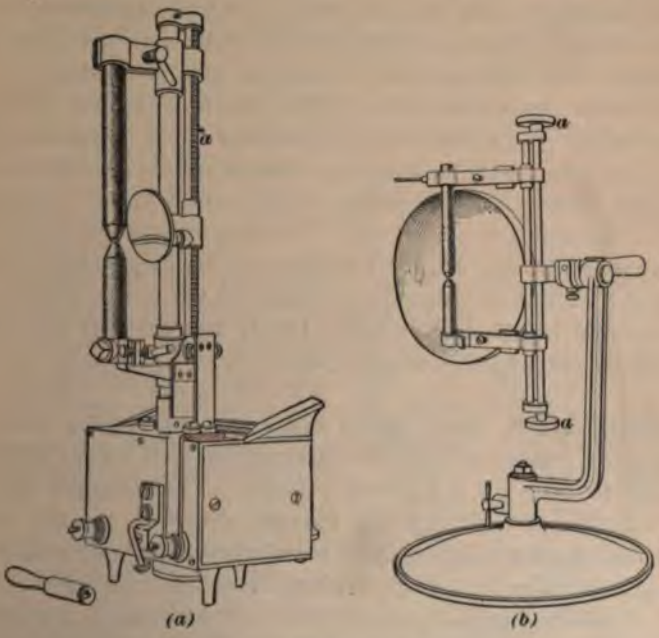


FIG. 56.

used. Fig. 56 shows another method of accomplishing the same result by using a special porcelain insulator that is made for this purpose.

SPECIAL APPLICATIONS OF ARC LAMPS.

102. Before leaving the subject of arc lamps we will take up, briefly, a few of the special applications to which the arc lamp has been put. Arc lamps are extensively used for stage illumination in theaters, for photo-engraving work, blueprinting, searchlights, or, in fact, any work where a strong light is necessary. For most of this work, the ordinary styles of arc lamp are not suitable, because such lamps are not of the focusing type. For projection work, it is necessary to keep the arc in a fixed position; in some cases this is accomplished by hand feeding, while in others the feeding is automatic. In Fig. 57, (*a*) shows an automatic focusing lamp and (*b*) a hand-feed focusing



(*a*) (*b*)

FIG. 57.

lamp. [illegible] lamp (*a*) is usually mounted on a stand and provided with accessories to suit it to whatever kind of work it is used for. It is designed for 20 amperes and is operated on direct-current circuits of 75 to 125 volts. The hand-feed lamp shown at (*b*) also operates normally at 20 amperes, but by using larger carbons, currents up to 50 amperes may be employed. The hand-feed lamp may also be operated with alternating current, but the alternating current is not very satisfactory for use in projection work. The hum caused [illegible] arc is often very annoying, and, moreover, the arc [illegible] ually shifting around. In both lamps shown in F[illegible] will be noticed that the carbons are fed togeth[illegible] ews and that the rate of movement is adjusted [illegible] the arc always remains stationary. If a lamp is [illegible] ed for short intervals only, the hand feed will be found quite satisfactory, because it is simple, cheap, and not liable to get out of order. If, however, the lamp is to be used for long runs, it is better to have an automatic feed. The lamp in Fig. 57 (*a*) is fed by the screw *a*, which is rotated by means of the lamp mechanism contained in the case below. In (*b*) the carbons are regulated by turning the knobs *a*, *a*.

103. When these lamps are run on a regular 110-volt circuit, a rheostat must be inserted in series with them in order to take up the excess voltage. The rheostat should be capable of carrying the current required by the lamp without undue heating, and should have enough resistance to give a maximum drop of about 70 to 80 volts when used on 110-volt circuits. About 20 to 30 volts of this drop should be adjustable, so that the current taken by the arc can be kept at the proper amount. For example, a lamp taking 20 amperes should have about 3½ ohms in the rheostat, and at least 1 ohm of this should be split up into 10 or 15 sections and connected to a regular rheostat switch so that a good adjustment can be obtained. A 10-ampere lamp would require about 7 ohms in the rheostat, and 2 or 3 ohms of this should be adjustable.

SEARCHLIGHTS.

104. One of the most important applications of the arc light for projection purposes is found in the searchlight. These are now used extensively both on shipboard and also on land, and reference has already been made to the arrangement of the carbons and mirrors as used in them. A searchlight is designed to concentrate the rays emitted from the crater of the positive direction and to project them so that they will be parallel to each other. A beam of light that does not spread out will illuminate objects at great distances, because the intensity of such a beam does not fall off with the square of the distance as does the light from an ordinary source. In fact, if all the rays were exactly parallel and the mirrors perfect and if there were no absorption of light by the atmosphere, the intensity of the beam would not diminish at all. As a matter of fact, it does diminish to an extent that depends very largely on the condition of the atmosphere.

For many of the following points and illustrations relating to searchlights we are indebted to a paper by Lieut. B. T. Walling published in the Proceedings of The United States Naval Institute. The type of lamp here described is one designed by the General Electric Company and which is used very largely both for naval and commercial work.

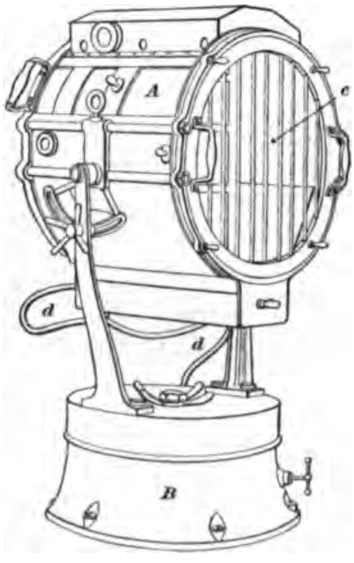


Fig. 58.

105. General Construction.—Fig. 58 shows a 24-inch projector. The barrel *A* contains the lamp and reflector, the reflector being mounted in the back end. This barrel is swung on trunnions supported by the base *B* and is arranged so that the projector can be swung around through any angle. The barrel can also be swung up and down or clamped in any desired position by

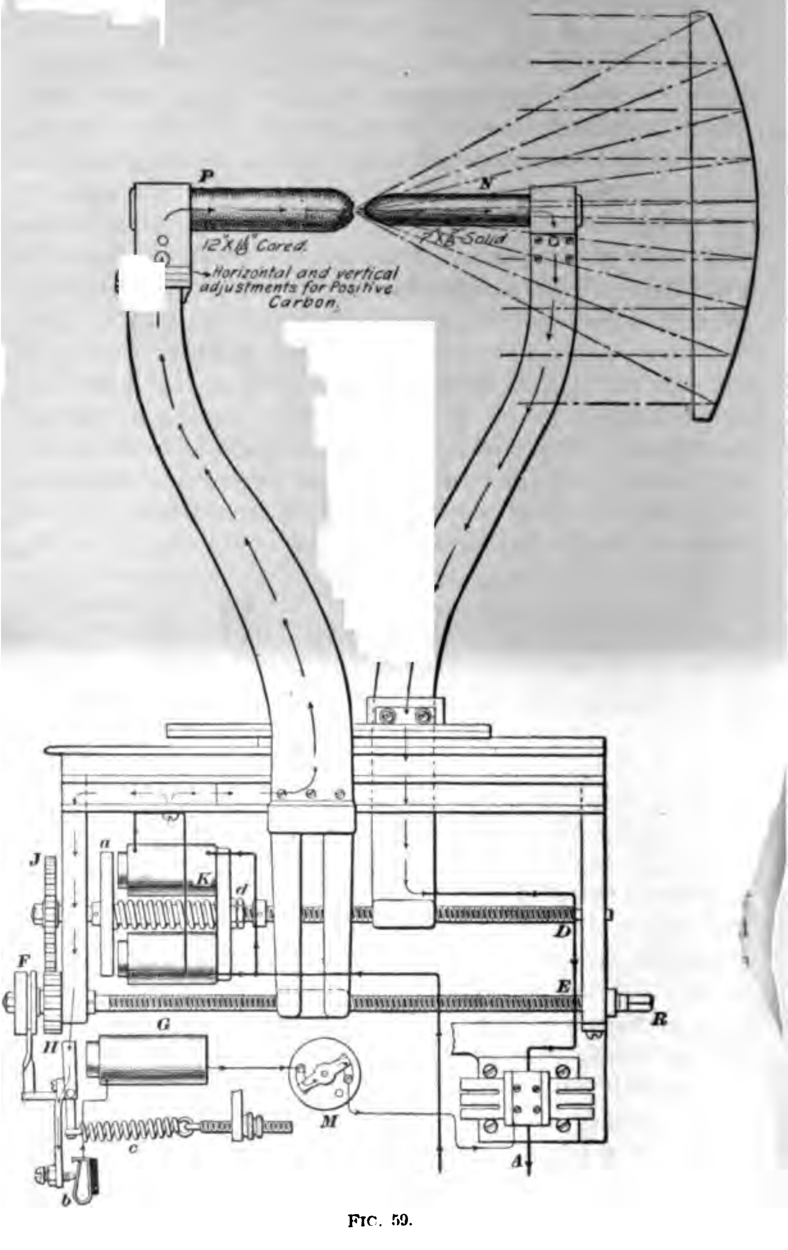

P
N
12" X 1⅛" Cored.
7" X ⅝" Solid
Horizontal and vertical adjustments for Positive Carbon.
J
a
K
d
D
F
E
R
G
H
M
c
b
A

FIG. 59.

ans of the fittings shown. In this projector these move- nts are accomplished by hand, but in many of the pro- tors used for naval work the movements are brought about small motors mounted in the base, so that, if desired, the archlight may be controlled from a distant point by run- ng cables from the projector to a controller situated at hatever point the searchlight is to be controlled from. he door of the projector is made of strips *c* of plate glass n order to avoid breakage and also to allow broken fronts o be easily repaired. Current is carried to the lamp by means of cables *d*, *d*, which connect to sliding contacts in the base.

106. Mirrors.—The mirrors or reflectors used in the better class of projectors are of glass, ground carefully and silvered on the back. Parabolic reflectors are used in the navy, as they throw a more powerful beam than the Mangin mirror or concave mirror. For commercial projectors, the Mangin mirror is used, and where cheap projectors are required or in case the projector has to stand a great deal of moving around, it is customary to use copper reflectors silvered on the inside surface. The lamp must be adjusted so that the crater comes at the focus of the mirror, otherwise the light will not be thrown out in parallel rays. The crater must, of course, face the mirror.

107. Searchlight Lamp.—Fig. 59 shows a type of lamp now used both for commercial and naval work. In this lamp the carbons are horizontal, the positive carbon being larger than the negative and pointing directly at the mirror. Some changes have been made in the later lamps from the construction shown in Fig. 59, but the principles involved are the same. The lamp has what is called a **ratchet feed** and is provided with two magnets—a series magnet that serves to strike or start the arc and a shunt magnet that works the ratchet feed.

Referring to Fig. 59, the shunt magnet is shown at *G* and the series magnet at *K*. *P* is the positive carbon and *N* the negative. *M* is a small switch for cutting off the current from the shunt coil when it is desired to feed the lamp by hand. The lamp may be fed by hand by slipping on a crank wrench at *R*. Screw *D* feeds the negative carbon and *E* the positive, the two screws being geared together at *J*. Current is led into the lamp by means of two sliding contacts *A*, one of which is shown in the figure, the other being directly behind *A* on the other side of the lamp. *H* is the armature of the shunt magnet and *F* the pawl-and-ratchet mechanism by which screw *E* is turned. The lamp for a 30-inch projector takes from 75 to 90 amperes, and for an 18-inch projector the current is from 25 to 35 amperes. The working current varies with the size of the lamp and also with the size of the carbons used. The voltage required at the lamp is usually from 45 to 49 volts and the feed will frequently operate when a pressure of 50 volts is reached.

108. The method of operating the lamp is as follows: The carbons are adjusted by the crank wrench to a separating distance of about ½ inch. The switch *M* is next closed. The main switch is closed next, and as no current can pass between the carbons, the voltage between them and, hence, the voltage across the shunt magnet *G* must be equal to the full-line voltage. The consequence is that armature *H* is attracted. As soon as *H* is attracted, the current through the shunt circuit is broken by the contact device *b* and the armature falls back and the attraction is again repeated. The armature *H*, therefore, vibrates rapidly and works a pawl that shoves the ratchet *F* around and feeds the carbons together. The screws are geared together, so that screw *D* revolves one-half as fast as *E*. As soon as the ratchet feed brings the carbons into contact, a heavy current flows for a short interval and the series coils *K* pull back the armature *a* and thus start the arc. As the carbons burn away, the voltage across *G* increases until the ratchet feed operates and moves the carbons a little nearer together. The point of feeding can be adjusted by means of the spring *c* and the length of the arc by means of nuts *d*. The positive carbon holder is provided with vertical and horizontal adjustments, so that it can be accurately lined up.

109. Naval searchlights are usually operated on 80-volt circuits, so that it is necessary to take up but 20 to 30 volts in the rheostat. For commercial lamps, the line voltage is higher, but in any case the rheostat should be adjusted so that the lamp will operate without hissing or flaming. With the horizontal type of lamp here described there is a tendency to flame at the upper edge of the crater, thereby forming the crater on the upper edge of the positive carbon and distorting the reflection. This tendency is corrected by a horseshoe magnet, which draws down the arc.

110. Some hissing will occur when starting up, especially with new carbons, and the lamp will not quiet down until a good crater has been formed in the positive carbon. This can be obviated by reaming out a crater in the positive carbon with a penknife before putting it in the clamp. Flaming and hissing are promoted by inferior carbons and are much increased if the carbons have absorbed oil. Carbons should be hard, homogeneous, and of the best quality. Soft carbons fuse and form "mushrooms," which cut off a large portion of the light and make the arc unsteady. The positive carbon should be cored, as this assists in holding the arc central and in making a good crater. Negative carbons are sometimes cored, but this is not generally considered necessary or even desirable.

111. Points Relating to Care and Operation.—When the searchlight is first started, an abnormal current will flow for an instant when the carbons touch each other. This current may be sufficient to throw the ammeter off the scale, but it does no particular harm if it does not continue. If it should continue, on account of the lamp failing to work properly, cut off the current at once by means of the main switch. The starting current may be as much as 50 per cent. above the working current. Any abnormal current of the searchlight ammeter is usually traceable to either a mushroom on the negative carbon or careless handling of the hand feed. If the lamp does not feed properly, it is because there has been a burn-out or that the lamp itself is not clean; in the great majority of cases dirt is the cause. The key to good searchlight operation is thorough cleanliness in all the parts and frequent opportunity for practice by those not ordinarily called upon. The mirrors will spot or frost in time, and this action is much hastened on board ship by the practice of exposing them to the rays of the sun while drying out the barrel. The action of direct sunlight will quickly ruin the silvered surface of a mirror. Every projector front should be fitted with an extra outside door to protect the glass front. Sometimes it is desired to use a beam of light that will spread out, and in such cases it is customary to fit the front with **diverging lenses** that are plano-convex strips instead of the plain flat strips ordinarily used.

ELECTRIC LIGHTING.

(PART 4.)

TESTING ARC-LIGHT LINES.

1. Since street arc-lighting circuits are generally long, considerably exposed, and of comparatively small wire, they always give more or less trouble on account of grounds, breaks, and crosses. Breaks are of quite frequent occurrence, especially during heavy wind or sleet storms, and very often cannot be detected by a mere inspection of the line. The wire may be broken while the insulation holds the ends together, so that, to all appearances, the line is intact. Breaks are especially liable to occur at the point where the line loops from the pole to the lamps.

Grounds are most likely to occur around the fronts of stores where the wires are run in proximity to iron awnings or fittings. Also, where the lines run through trees, there will always be more or less of a ground, especially in wet weather. In this case, however, the trouble would be more correctly termed a leak, as it is due to defective insulation and does not constitute a direct connection to ground, as would happen, for example, if one of the lines came into contact with an iron pole or a gas or water pipe.

Crosses are caused by one line coming into contact with another, and, under ordinary conditions, should not occur frequently if the line is well constructed. Of course, heavy storms, especially sleet storms, may cause a great deal of trouble on arc lines, but we are now speaking of the troubles that are liable to occur under ordinary working conditions.

§ 19

For notice of copyright, see page immediately following the title page.

All arc lines should be tested at intervals during the day to see if any faults have developed, so that they may be looked up and remedied, if possible, before it comes time to start up in the evening. There are various methods of testing for grounds and breaks, but in the great majority of cases they are located by the use of an ordinary magneto-bell. Such a bell is very convenient for testing purposes, as it requires no battery for its operation and is able to ring through a long length of line; moreover, it is easily carried around from place to place. Another testing instrument that will be found very useful around an arc station is a portable Wheatstone bridge. These are now made in a variety of forms that are compact and convenient to work with. They are often very useful in locating faults on lines, but more particularly for making measurements of resistance on dynamo armatures and fields, arc-lamp spools, etc.

2. Locating Breaks.—Series arc circuits should be frequently tested for breaks by connecting a magneto to the terminals of the circuit, at the station, and ringing it up. If the bell fails to ring, it shows that the circuit is broken somewhere and the break should be looked up at once. If the circuit is aranged in loops that may be cut out by means of switches on the poles, the first thing to do is to cut out the loops in succession until a ring is obtained. This will show in which loop the break is, and the fault may then be further located, as described later; or, in many cases, it

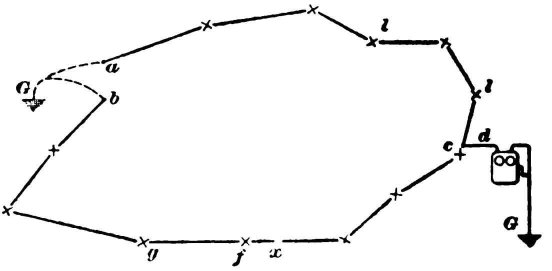


FIG. 1.

may be found by a simple inspection. In general, however, the problem will be to locate a break on a simple series circuit, such as that shown in Fig. 1. The irregular outline here represents the circuit, or portion of a circuit, of which *a*, *b* are the terminals; *l*, *l*, etc. represent the lamps. It is found by ringing up between *a*, *b* that there is a break on the circuit. We will indicate this break at the point *x*, though its location is not known as yet. The first thing to do is to connect *a* and *b* together and ground them, as shown by the dotted lines. The lineman then goes out to the point *c*, as near the middle of the circuit as possible, and opens the circuit by lowering a lamp and removing the wires or in any other way that may be convenient. He then attaches one terminal of the testing magneto to ground, by connecting it with a hydrant or other ground connection that may be at hand, and the other terminal to one end of the circuit *d*. He then rings up, and if the bell rings, it shows that the portion of the circuit from *d* around to the station is all right and that the break is in the other half. He then closes the circuit at *c* and moves on to a place *f*, about half way between *c* and the station. The circuit is here opened and the magneto-bell connected as before. If a ring is obtained when the bell is connected to the left-hand end of the line, it shows that the stretch of circuit *f*-*g*-*b* is intact; while, if the bell does not ring when connected to the right-hand side, it shows that the break is between *f* and *c*, because the previous test showed that the part *d*-*l*-*l*-*a* was all right. In this way, by making a few tests, the lineman can locate the stretch of circuit in which the break occurs between narrow limits, and the break itself can then usually be located by a careful inspection.

3. Locating Grounds.--When a line becomes grounded at any point *x*, as indicated in Fig. 2, the ground may be located by using a magneto, in which case the ends of the line *a*, *b* at the station are left open, instead of being grounded, as when testing for breaks. The line is then opened about the middle point *c* and each side rung up, one terminal of the magneto being connected to the ground. It is evident that the side on which a ring is obtained is

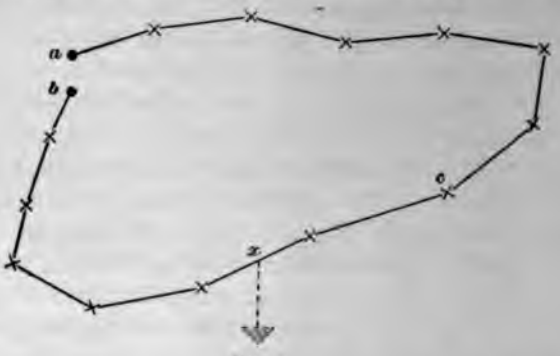


FIG. 2.

the one on which the ground exists. The half on which the ground is located is then opened at its middle point, and, in this way, the part of the line that is grounded is soon located within narrow limits.

4. Locating Grounds by Means of Voltmeter.—If a high-reading voltmeter is available, it may be used for locating grounds on an arc circuit, as indicated in Fig. 3.

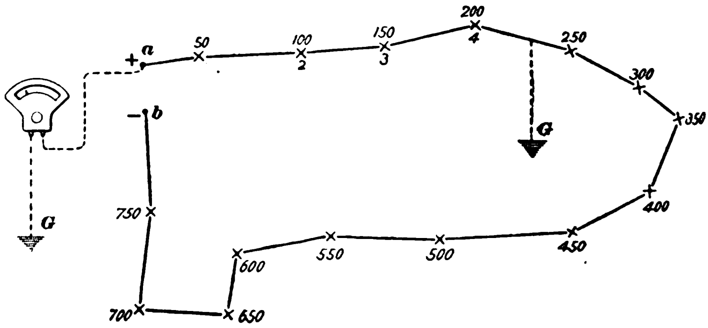


FIG. 3.

The dynamo is here omitted, but it is supposed to be operating the circuit connected to its terminals *a*, *b*.

In this case we have, say, 15 lamps operated on a circuit.

The total pressure generated by the dynamo will then be about 15 × 50 = 750 volts, allowing 50 volts per lamp. The difference of potential between the negative side of lamp *1* and $a+$ will be 50 volts, between the negative side of *2* and $a+$ 100 volts, and so on, as shown in the figure. If we connect one terminal of the voltmeter to $a+$ and the other to ground, we will get a reading whenever there is a ground on the line. Suppose, for example, that there is a ground at *G*. We will then have the voltmeter connected across four lamps and it will give a reading of about 200 volts. The voltmeter reading, therefore, indicates how far the ground is out on the line. If, for example, we obtained a reading of about 100 volts, we will know that the ground is somewhere between the second and third lamps.

5. Differential Method of Locating Grounds.—This method consists in balancing the drop through an artificial line against the drop through the portion of the circuit from the station to the point where the ground exists. The method will be understood by referring to Fig. 4.

The terminals of the circuit are indicated at *a*, *b*, and, for the sake of illustration, we have shown 10 lamps. The total pressure generated by the dynamo will be about 500 volts, and the drop in pressure between $a+$ and different points on the circuit will increase as the lamps are passed, as shown by the numbers *50*, *100*, etc. The testing apparatus consists of a number of *equal* resistances *1*, *2*, *3*, *4*, etc. connected in series with terminals brought out to a switch, as indicated. These resistances should be fairly high, say about 50 ohms each. Ordinary 52-volt incandescent lamps will answer. A detector galvanometer *C* is connected to the switch blade and to the ground. Any instrument that is reasonably sensitive will do, as it is not necessary for it to read either volts or amperes. This device should have as many resistances as the greatest number of lamps on any circuit that is likely to be tested. One end *x* of the resistance is connected to $a+$. The other end of the circuit $-b$ is connected at the point *z*, so that the number of resistances will correspond to the number of lamps on the circuit to be tested. The switch arm is then moved over to the right until the galvanometer deflection comes to zero. In this case, the deflection will become zero when the arm is at the point *y* between resistances 6 and 7. It is evident that the fall of pressure from *a*+ through the artificial circuit corresponds to the fall in pressure from *a*+ around the arc line; hence, when a point is reached when the drop in pressure from *a*+ around to the ground is equal to the drop in the artificial line, the two pressures counterbalance each other, as indicated by the arrows, and no current flows through the galvanometer. As soon as the point corresponding to that where the ground exists is passed on the switch, the galvanometer will reverse its deflection.

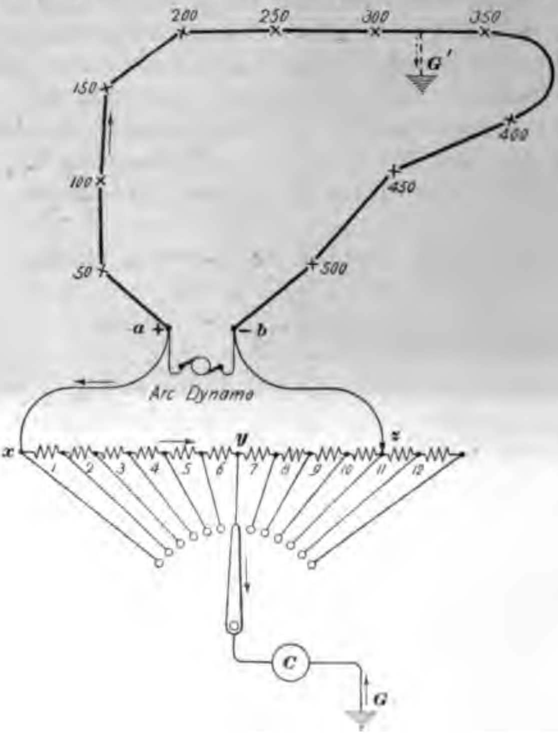


FIG. 4.

LIGHTNING PROTECTION FOR ARC CIRCUITS.

6. Series arc-light circuits are very apt to bring in lightning discharges to a station, because they cover such large areas and are usually pretty well exposed. They should, therefore, be well protected by lightning arresters. The arresters used on arc circuits differ little, if any, from those used on other circuits. Care must, of course, be taken in selecting an arrester to see that it is adapted to the voltage of the circuit. Many of the older types, which were quite satisfactory on circuits operating as high as 60 to 75 lamps, are not suitable for high-voltage circuits operating 125 to 150 lamps. If the older types of arrester are to be operated on such circuits, two of them should be connected in series.

7. Thomson Arrester.—Fig. 5 shows the Thomson magnetic blow-out arrester that has probably been used in the past more extensively on arc circuits than any other one type. It is similar in principle to the blow-out arrester used on constant-potential circuits, except that the coils are in series with the dynamo instead of being connected across an auxiliary air gap. The coils, therefore, carry the current all the time the dynamo is in operation. There is little objection to this in the case of an arc circuit where the current is small. For constant-potential circuits it would be inconvenient to carry the main current through the

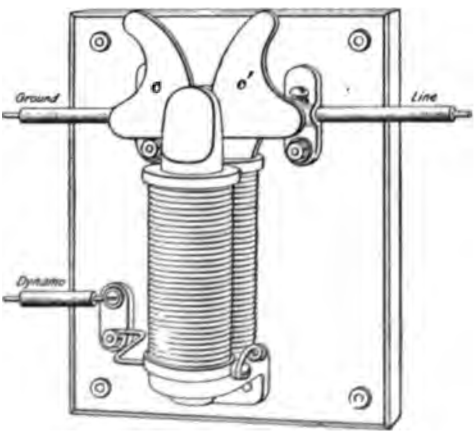


Fig. 5.

blow-out coils, and unless they were of very low resistance there would be considerable loss of energy. The air gap is between the vanes *c*, *c'*. Fig. 6 shows how the arresters are connected. Current from the dynamo *D* flows through the coils *A* and out on the line, thus setting up a magnetic field between the pole pieces. When a discharge comes in over the line, it jumps from *c'* to *c* and passes off to the ground. The coils *A*, *A* act as choke, or reactance, coils to keep the discharge out of the dynamo, but sometimes additional choke coils are inserted, as shown at *L*, *L*, in order to make the protection still more sure. This same style of arrester is mounted in a weather-proof box for use out on the line; the one shown in Fig. 5 is intended for use in the station. Fig. 7 shows two of these arresters connected in series for circuits on which more than 75 lights are operated.

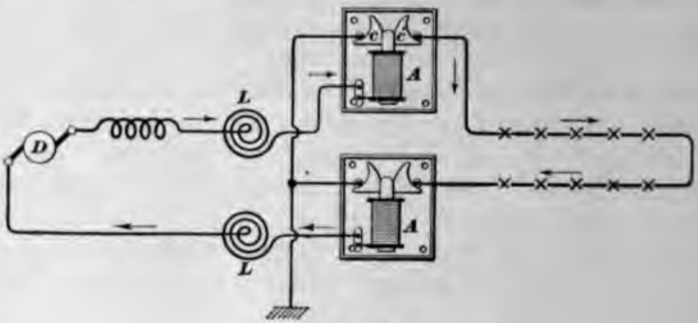


FIG. 6.

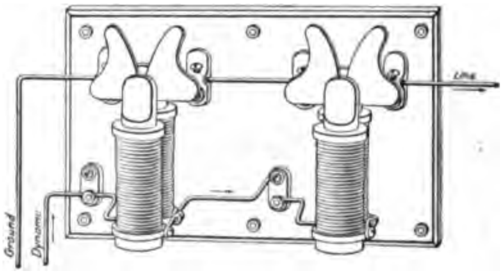


FIG. 7.

8. The type of blow-out arrester described in *Electric Lighting*, Part 2, and made by the General Electric Company for use on direct-current lighting and power circuits, is now also used on arc-light circuits. This arrester has a smaller air gap than those just described and, hence, affords a better protection especially against static charges that gradually accumulate on the lines and do not take the form of a regular lightning discharge. Moreover, as the working parts of this arrester are mounted in a porcelain case, there is much less liability of dust and dirt becoming lodged in the air gap.

9. The arresters just described are, of course, intended for use with direct current. For alternating-current systems, the arresters described in *Electric Lighting*, Part 2, in connection with alternating-current incandescent circuits may be used.

10. Lightning Arrester for Arc Lamps.—Although lightning may not get into the station, it sometimes punctures the insulation of the lamps out on the line and is responsible for many burned-out coils. In order to prevent this, small arresters, or, rather, simply spark gaps, may be connected across the terminals of the lamp. Fig. 8 shows a simple arrester for this kind of work. This consists simply of two brass cylinders with a small gap between them. When a discharge comes along the line, it will jump between the cylinders and thus pass along to the regular lightning arresters, which will

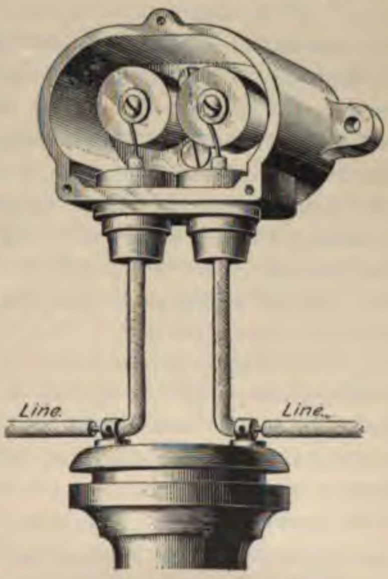


FIG. 8.

carry it to ground. The lightning will jump the gap in preference to passing through the lamp on account of the self-induction and consequent reactance of the regulating coils in the lamp.

11. It will generally pay to have a number of arresters, connected between the line and the ground, distributed over the line instead of depending on the station arresters alone for protection. All arresters should be provided with a good ground connection, otherwise they will be of little value.

STATION EQUIPMENT.

12. General Remarks.—Having considered the lamps themselves and the line used to convey the current to the lamps, next in order comes the apparatus for the generation and control of the current supplied to the various arc circuits. This means a consideration of arc-light dynamos, switchboards, and methods of operating arc lights by alternating current. Attention has already been called to the fact that large numbers of arc lamps are run on constant-potential circuits. These lamps are operated by the same machines and from the same mains used for the incandescent lighting, so that the equipment described in *Electric Lighting*, Part 1, is suitable whether the lamps be direct or alternating. We will, therefore, confine our attention to the special equipment necessary for operating constant-current series circuits.

13. Lamps may be operated in series by means of a constant current, either direct or alternating. In case direct current is used, it is supplied by regular arc-light dynamos. In case alternating current is used, it is generally supplied from a constant-potential alternating-current dynamo supplying the lamps through a regulator or transformer of some kind that will serve to keep the current at the correct value, no matter how many lamps there may be in the circuit. Constant-current alternators have not as yet been used to any great extent, but as the use of series alternating arc lamps extends, it is quite probable that they may be used more than has been customary in the past.

CONSTANT-CURRENT ARC-LIGHT DYNAMOS.

14. The constant-current arc-light dynamo may in many ways be considered as a decided contrast to the constant-potential direct-current machines used for low-pressure lighting or street-railway work. In the first place, arc machines must generate a comparatively small current (from 6 to 10 amperes), but the maximum pressure that they are called upon to deliver at full load is very high. Moreover, they must be constructed so as to keep the current at the required amount through a wide range in the number of lamps operated.

The constant-potential dynamo does just the opposite. It maintains the pressure (usually from 110 to 600 volts) at a constant or nearly constant value and the current varies with the load. A constant-potential machine can be made self-regulating by providing it with a compound field winding. In order, however, to make a direct-current machine regulate for constant current, it is necessary to provide it with an electromechanical regulator of some kind that will adjust the voltage with changes in load, so as to keep the current constant.

These regulators are always more or less complicated. It is quite a common thing to go into arc-light stations and find the regulators thrown out of action. Some of them give so much trouble that the station men prefer to regulate the machines by hand rather than bother with them. Most of these regulators shift the brushes, and if the load does not change suddenly (as, for example, on a street-lighting circuit), the dynamo tender can regulate the current by watching the ammeter and regulating the position of the brushes by hand when necessary. On the other hand, many constant-current arc machines regulate almost perfectly and give very little trouble if the machine is only kept clean and in good condition.

15. For convenience, constant-current arc machines may be divided into two general classes: (*a*) those with open-coil armatures and (*b*) those with closed-coil armatures. The Brush and Thomson-Houston machines belong to the first class, and the Fort Wayne or Wood, Excelsior, Western Electric, and Ball belong to the second class.

OPEN-COIL MACHINES.

16. The Thomson-Houston (T. H.) Dynamo.—This machine has been very largely used for arc lighting and has given excellent service, notwithstanding the fact that its regulating mechanism is rather complicated and that, as a whole, it has more peculiarities than almost any other direct-current machine in common use. The General Electric Company, who succeeded the Thomson-Houston Company, do not now manufacture this type as their standard arc machine; but since large numbers of T. H. machines are in use, we will consider a few points regarding them.

Fig. 9 shows the general appearance of this arc machine, and Fig. 10 shows how it is connected with the wall controller and the lamp circuit. The arrangement of the plug switchboard, which is merely shown at *A*, Fig. 10, in order to make the diagram complete, will be fully explained later. *B*, Fig. 10, is the wall controller that is used to throw the regulating magnet *M*, Fig. 9, into or out of action whenever a movement of the brushes is necessary to keep the current constant. *R* is an adjustable rheostat connected in shunt with the right-hand field coil. Constant-current arc machines are always series-wound, i. e., the field coils are connected directly in series with the armature. If a shunt is connected across one of the field coils, as in this case, the current through that coil is reduced and the field is correspondingly weakened. This rheostat is used to improve the regulation of the machine when it is operated on a number of lamps considerably less than its normal capacity. The machines are, however, frequently operated without any rheostat, especially if they are worked at nearly full load. *W* is a recording wattmeter used to measure the total work done by the machine. The current coil of this wattmeter is connected in series with the dynamo and lamps, and the pressure coil is connected across the terminals of the dynamo in series with the resistance *r*.

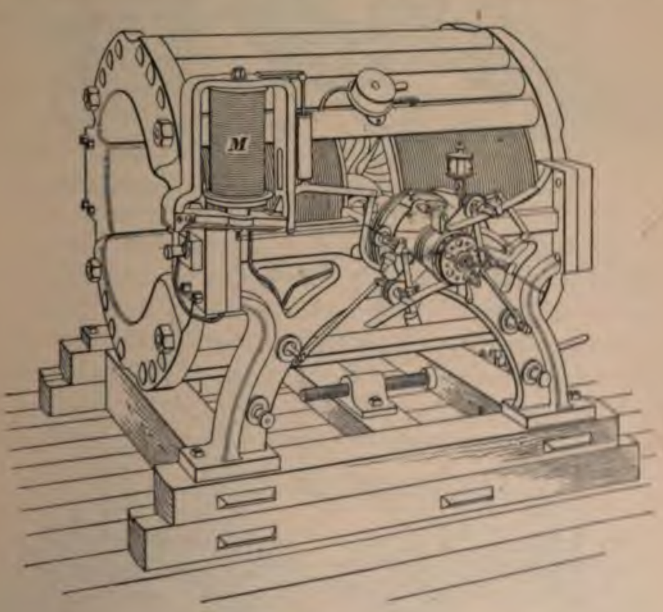


FIG. 9.

17. Armatures for T. H. Dynamos.—The old style T. H. armature was nearly spherical in shape, but it was essentially of the drum type, because the wire was wholly on the outer surface of the core and the coils overlapped. The objections to it were that it was difficult to wind, difficult to repair, and poorly ventilated. The later types of T. H. machines are, for these reasons, equipped with the ring-type armatures.

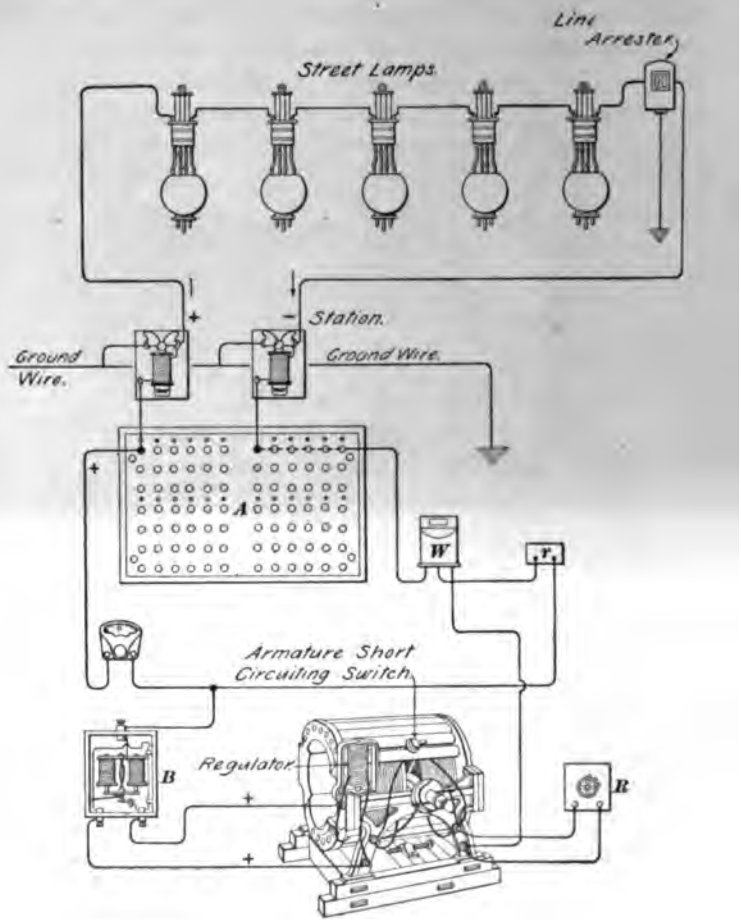


FIG. 10.

Fig. 11 indicates the construction of this later type of armature. In this figure, the spider that supports the core has been removed, and only a portion of the coils is shown in place, in order to indicate the method of construction. The core *A* is built up of sheet iron and has a slot *S* in it wide enough to admit the coils *c*, so that they may be removed if necessary. A laminated iron piece *b*, fitting into slot *S*, is held in position by end pieces and locks the core securely. The coils *c* are wound on forms and are heavily insulated. The core is supported by the radial arms of the armature spider which fit into grooves. This style of armature gives much better ventilation than the older type and is very much easier to repair in case a coil burns out.

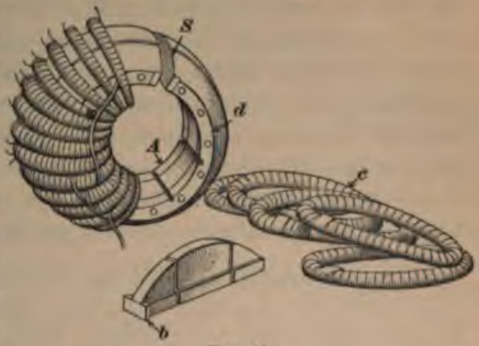
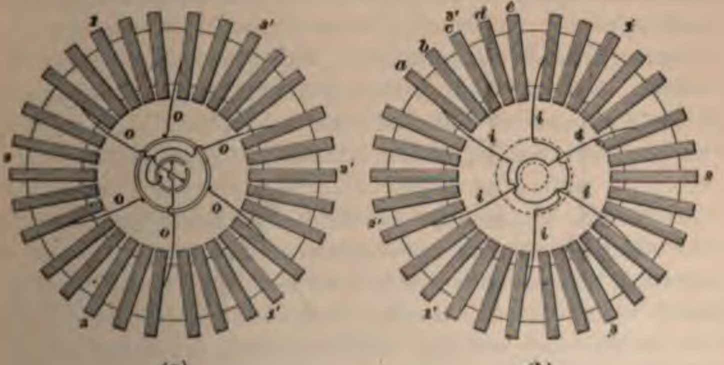


FIG. 11.



(a) (b)

FIG. 12.

18. The connections for the ring armature are the same in principle as those of the drum. The coils are divided into three groups and one end of each group is connected t junction. The remaining three ends are then carried the commutator segments. Fig. 12 (*a*) and (*b*) shows the connections of a T. H. ring armature, (*a*) being the connections as seen from the commutator end and (*b*) from the pulley end. The individual coils of each group, such as *a*, *b*, *c*, *d*, *e*, etc., are connected in series. The ends marked *i* are inside ends of coils; those marked *o* are outside ends. Outside of the change in the style of armature and some improvements in the bearings, the T. H. machine has been changed but little since it was first brought out.

19. General Remarks o H. Machines.—In operating the T. H. machine, care be taken to see that the brushes are correctly set, wi gard to the commutator, and also that the commutator roperly set on the shaft, with regard to the armatur istructions for doing this are furnished by the manu ers and a gauge is provided for setting the brushe ailure to attend to these points will result in "flashin the machine may refuse to pick up its load at all.

20. Flashing is a fault to which arc-light dynamos are especially subject. It consists in a momentary short-circuiting of the machine by an arc jumping around the commutator from brush to brush. This produces a flash, so well known in connection with these machines. It may arise from a number of different causes. In the T. H. machine, an improper setting of the brushes or commutator referred to above may cause it, also defects in the air blast. If the jets become stopped up or if the blower itself is out of order, the puffs of air will not be delivered so as to blow out the spark. This will allow it to carry over to the adjacent segment and a flash will result. A flash is immediately followed by a lowering of the regulator and must not be confounded with the ordinary sparking of the machine. When a T. H. machine is running under normal conditions, there is a spark about $\frac{3}{16}$ to $\frac{1}{4}$ inch long at the ends of the brushes. This spark has a violet tinge and does no special harm; in fact, an experienced hand can tell by the size and color of the spark if he has the brushes and commutator adjusted correctly or not. When flashing occurs, it generally indicates that something is wrong, and the trouble should be looked up and remedied. Bad contacts in the wall controller are another cause of flashing; an overload on the dynamo or a low speed will also give rise to it. Sometimes flashing is caused by a short circuit or open circuit in one of the armature coils. Trouble of this kind in the armature will, as a rule, not only cause bad flashing, but will also cause the brushes to spark much more than usual. Sometimes flashing occurs when there is no fault in either the wall controller or the dynamo. The wires may be crossed at some point on the line, so that as they sway back and forth, part of the circuit is cut in or out, thus throwing part of the load on and off. With some styles of differential lamps a break in the shunt circuit of one or more of the lamps will often cause flashing. Such a break may be caused by lightning and will prevent the lamp feeding when it should. The characteristic of flashing resulting from this cause is that it occurs at regular intervals. As the carbons of the faulty lamp burn away they become farther and farther apart, because the shunt coil is out of action and cannot make the lamp feed. The resistance of the arc finally becomes so great that the dynamo can no longer keep the current constant and the machine finally flashes. This momentarily cuts off the current from the circuit, so that the carbons drop together and the same performance is repeated.

21. Sparking. — As already stated, T. H. machines always run with a spark, even when they are in perfect condition. Sometimes, however, they spark more than they should, and in such cases the trouble should be looked up. Inaccurate setting of the brushes, loose brushes, or loose commutator segments will cause sparking. Defects in the air jets, dirty commutator, too much oil on commutator, and ragged or bent brushes are other causes. Sparking is sometimes caused by the dynamo generating a larger current than it should If this is the case, it will be indicated by the ammeter, and the wall controller should be inspected and adjusted. On account of the peculiar construction of the T. H. machine, there are a great many things that may give rise to flashing and sparking. Those given above are a few of the more important ones. It must not be inferred, however, that the machine is not satisfactory on this account. In fact, there are few arc dynamos that have given such generally good service as the T. H., and after a man has worked around them a while he soon becomes accustomed to the method of handling them and has very little trouble. The wall controllers require scarcely any attention and will work year in and year out without giving trouble. The T. H. machine has been replaced by other types, not because it was unsatisfactory, but because of the demand for larger machines of higher efficiency which could handle a larger number of lamps. Most of the older styles of constant-current arc dynamos had a very low electrical efficiency compared with constant-potential dynamos of the same output.

22. The Brush Arc Dynamo.—The old style Brush arc machine was very simple in construction. Large numbers of these machines are still in use, but they are gradually being replaced in the larger plants by the later style shown in Fig. 13. These machines are much larger than the bipolar type and have a higher efficiency. The armature *M* is of the ring, open-circuit type, and its general construction is the same as that of the older style armature with a number of improvements in the mechanical details and method of insulation. The connections are also slightly different in order to adapt the armature to a four-pole field. Instead of connecting diametrically opposite coils in series, as in a two-pole machine, four coils situated one-quarter of a circumference from one another are connected in series and the terminals brought out to the commutator segments.

The field is the same in some respects as that on the old machine, but there are four poles on each side of the armature instead of two. On each side the poles are alternately north and south, but poles directly opposite each other are of the same polarity. For example, in Fig. 13, poles *A*, *A* are alike and of one polarity, while *B*, *B* are also alike but of opposite polarity to *A*, *A*. In placing and connecting the field coils, the instructions sent out by the makers should be followed carefully, and it is always a good plan to send current through the coils and test the polarity with a compass before starting up the machine.

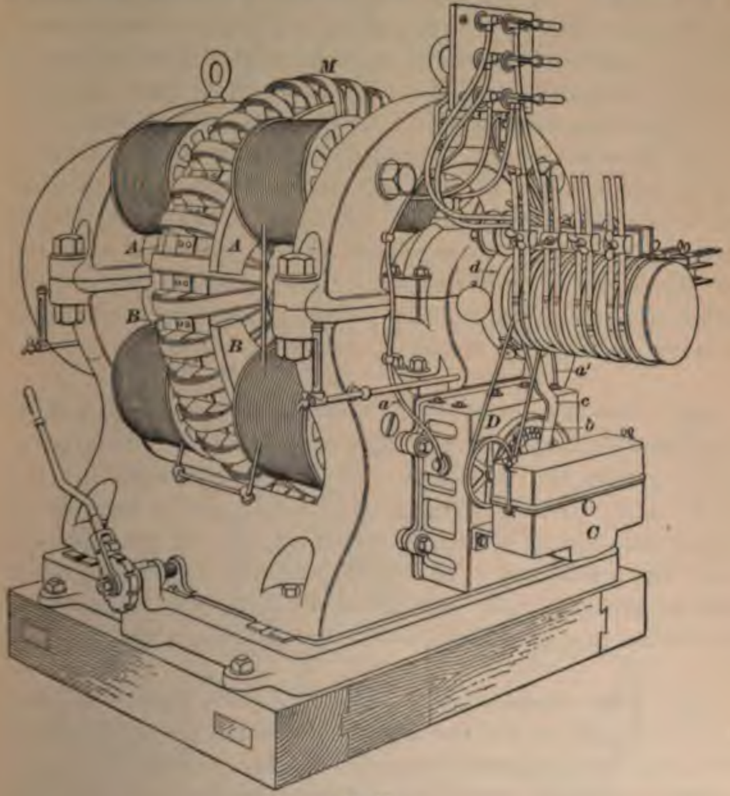


FIG. 13.

23. The other chief point of difference between the new-style and old-style Brush machine lies in the regulator. The old regulator was entirely separate from the dynamo and took the form of a carbon resistance connected in shunt across the terminals of the field. This resistance was made of a pile of carbon plates that were pressed together by a lever pulled by a magnet connected in series in the circuit. If the current increased, the magnet pulled on the lever and pressed the plates together, thereby lowering the resistance in shunt with the field. This allowed a greater proportion of the current to flow past the field windings, thus cutting down their magnetizing power, lowering the voltage, and bringing the main current back to its proper value. If any regulation of the brushes were necessary to prevent undue sparking, it was accomplished by hand. In the later machines the regulator is mounted on the dynamo and not only varies the amount of the resistance shunted across the field, but also tips the brushes so as to regulate the sparking.

24. The regulator, Fig. 13, is in the box *C* and will be described in detail later. The rheostat *D* is connected in shunt across the terminals of the field by means of the wires *a*, *a'*. This resistance is divided into a number of steps, connections to which are made by an arm moving over the contacts *b*. This arm is moved by the regulator and at the same time the brushes are tipped by means of the rocker-arm *c* attached to the brush-holder yoke *d*.

25. The Regulator.—Two types of regulator have been brought out for the multipolar Brush machines. The first type used magnetic clutches to move the rheostat arm. A shaft on which were mounted two magnetic clutches was driven at a uniform speed by a belt from the main shaft. The shaft carrying the rheostat arm was moved by the clutch shaft by means of beveled gears, so that when current was allowed to pass through one clutch, the rheostat arm was moved in one direction, and when the other clutch was thrown into action, the arm was moved in the opposite direction. The current through the clutches was regulated by a wall controller. This controller consisted of two series magnets provided with armatures carrying contacts, so that when the current became low one clutch was energized, and when too large, the other. This form of regulator is not now manufactured, so that it will not be necessary to describe it in detail. The one now made is shown in Fig. 14. This regulator is shown at *C*, Fig. 13, but Fig. 14 is a larger

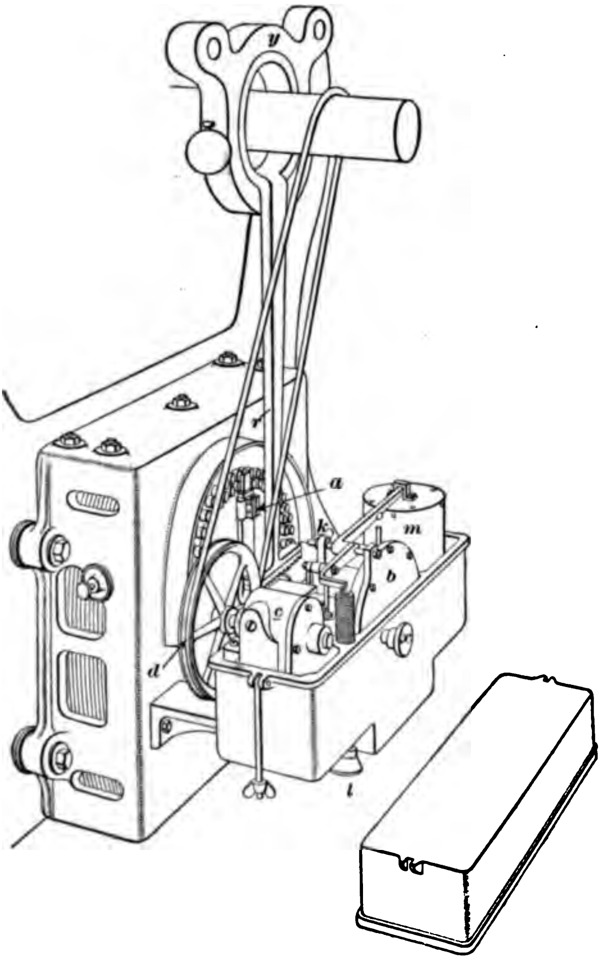


FIG. 14.

view, showing the regulator with its rheostat detached from the machine. It requires no wall controller and is operated by an encased magnet *m* connected in series with the lamps. The magnet *m* does not move the rheostat arm *a*, but simply controls a valve that admits oil under pressure to either side of a vane or piston that swings around in the closed chamber *b*. The oil pressure necessary to operate the piston is maintained by means of a small rotary pump *c*

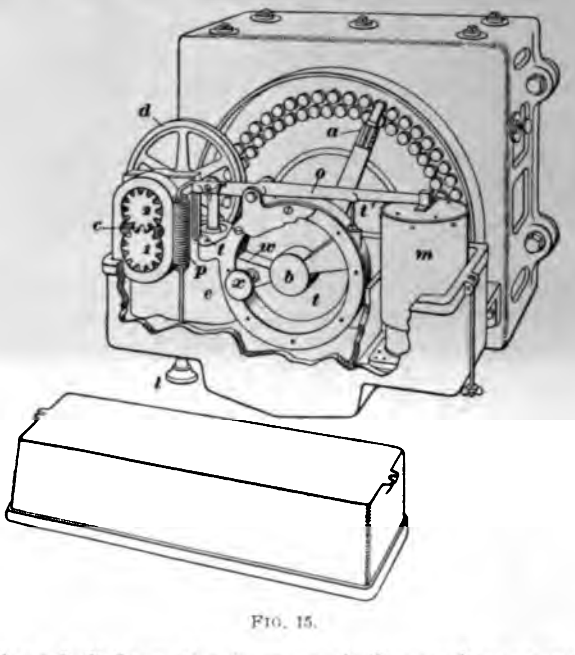


FIG. 15.

driven by a belt from the dynamo shaft running on pulley *d*. The lower case is filled with oil to a point a little below the rheostat-arm shaft.

Fig. 15 shows the working parts of the regulator with the outer casing removed. The pump consists of two gears 1, 2, Fig. 15, meshing with each other. Oil is drawn from the lower part of the box and discharged through the valve, [illegible] up and down in a chamber at *e*. The series [illegible] pulls on the lever *o*, which operates against adjusting spring *p*. The valve is operated by means of link *r*. The piston or vane *b* is movable and is free to ng around in the chamber *t*. The partition *w* is fixed, so t when oil is pumped in above *w* and is allowed to flow below, the vane *b* moves clockwise and moves the rheo- arm in the same direction. When oil is pumped in on lower side and allowed to flow out on the upper, the e moves counter clockwise. When the current is at its mal value, the valve is in its central position and the ports

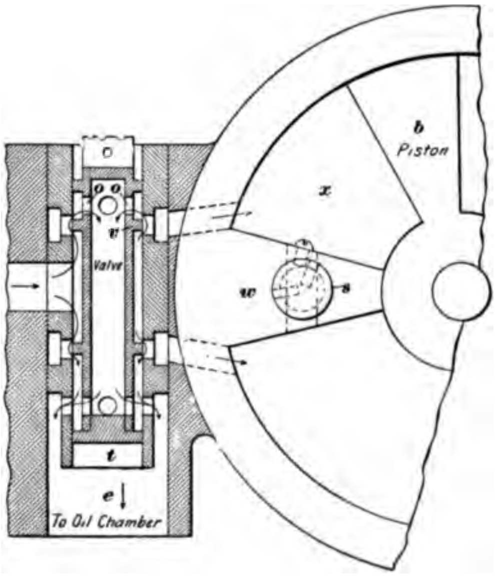


FIG. 16.

arranged so that the oil passes in and out of the valve mber without affecting the piston. Under such circum- nces, therefore, the rheostat arm remains stationary.

ig. 16 shows the arrangement of the valve. It is here wn in its mid-position and the arrows show how the oil rs past the valve and back into the chamber. When the ve is raised slightly, the flow through the ports *o*, *o* is pped and oil is forced into the chamber *x*, thus for- g the piston to the right, or clockwise. As soon as the current has regained the normal amount, the valve again assumes the central position and the oil flows through it as before. If the current falls below normal, the magnet becomes weakened and the valve moves below the central position. In this case the upper chamber *x* is cut off from the pump, but is opened to the outside while the corresponding lower chamber is opened to the pump and cut off from the outside and the vane or piston *b* is forced to the left, or counter clockwise. The valve *s* is used to make an opening between the two chambers, so that the action of the regulator may be stopped when desired. Any adjustment that may be found necessary is made by varying the tension on spring *p*, Fig. 15, by means of the knob *l* at the bottom of the case. The quickness of action can also be regulated by varying the length of the stops *t*, *t'* on the lever *o*, Fig. 15.

26. In addition to moving the rheostat, the regulator also tips the brushes by means of an arm extending down from the rocker and carrying a toothed arc that engages with a small spur wheel on the shaft carrying the rheostat arm. By this movement the brushes are adjusted with the changes in load so as to keep the spark at the brushes about $\frac{3}{8}$ inch long on short circuits and $\frac{1}{8}$ inch long on full loads.

Some of these machines are provided with what is called a **spark-controlling switch.** This is an adjustable resistance in series with the rheostat. By varying this resistance, the field strength of the machine may be adjusted, to a certain extent, independently of the position of the rheostat arm, and the field strength determines, to a large extent, the amount of sparking. On these machines the spark at the negative brush (the top or horizontal brush) follows the brush in a zigzag line, while that on the positive, or vertical, brush follows the brush in a straight line.

27. The controller described above will hold the current at its correct value with very little variation either way.

Its chief advantages over the magnetic clutch controller are that it requires no wall controller and it is not so liable to give a seesawing effect. The regulation is brought about more evenly than when clutches are used and is not so liable to overshoot the mark and then have to be brought back again, thus giving rise to surging effects in the current. The oil regulator is comparatively simple in construction, and there are few parts of it that are liable to give trouble, and the moving parts run in oil, so that the wear is very slight. A light dynamo oil should be used, and when the machine is first installed the old oil should be drawn off and replaced by new at least once a week until all grit and dirt have been cleaned out. The cover must never be left off the regulator.

28. Connections of Multipolar Brush Arc Dynamo. The number of coils on the armature and the number of commutators depends on the size of the machine. The larger sizes have four commutators and the smaller three. Each group of coils, with its commutator and brushes, may be considered as a dynamo by itself, because the various sets of windings have no connection with one another unless they are connected through the outside circuit. On account of having this style of armature winding with a number of separate commutators, the machines may easily be connected so as to operate a single circuit or a number of circuits, as previously explained.

CLOSED-COIL MACHINES.

29. The Wood Arc Dynamo.—This machine has a simple closed-coil ring armature and a commutator divided into a large number of segments so as to make the voltage between segments low and prevent undue sparking. Fig. 17 shows one of these machines of 125 lights capacity, and, therefore, capable of generating about 6,250 volts at full load. The controlling magnet *m* of the regulator here shown is connected in series with the line and operates the lever *n*. The brushes are moved by means of a small double friction clutch that is contained in the casing shown at *a*. When the lever is pulled up beyond the normal position, the clutch moves the brushes forwards by means of the gears *b*, *e*, *d*, thus lowering the current. If the current becomes too weak, the lever moves down and the clutch moves the brushes back, thus increasing the current. These machines operate on a single circuit and are made as large as 150 lights capacity. The largest size of machine is of a somewhat different design from that shown in Fig. 17, but the principle of operation is the same. The connections used with the Wood system are very simple. The armature, fields, and regulating magnet are all connected in series, and the regulation is effected altogether by tipping the

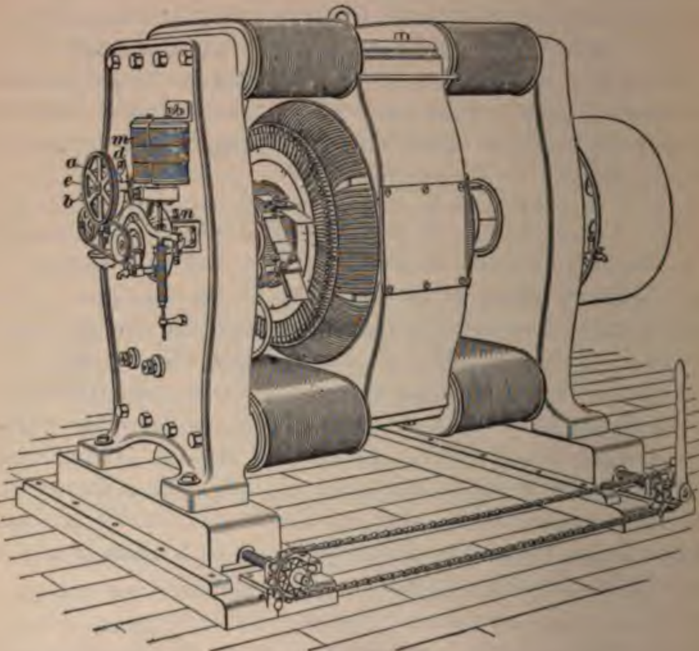


FIG. 17.

brushes, there being no rheostat of any kind in shunt with the fields.

30. The **Excelsior** and **Western Electric** machines also have closed-coil armatures. The larger sizes of the more recent Western Electric machines are of the four-pole type and have two pairs of brushes. This dynamo is provided with two regulators and supplies two circuits in parallel. Each of the regulators controls one pair of brushes. This is a somewhat different multiple-circuit arrangement from that of the Brush machine, because there the two loops or circuits are in series and the current is bound to be the same in each, hence only one regulator is needed. Moreover, if the circuit is opened at any point, the full pressure of the dynamo is obtained at the break. When the circuits are in parallel, it is evident that each circuit must have a regulator of its own, but under no circumstances can the pressure obtained exceed that which is ordinarily applied to one circuit, i. e., half the pressure that the machine would have to generate if all the lamps were connected in series.

31. General Remarks.—From the above it will be noticed that the general tendency has been to produce arc machines of larger output rather than to make any radical change in the design. The most modern Brush machines are almost exactly the same, so far as general principles are concerned, as those first manufactured. When it comes to making large constant-current machines, however, difficulties are met with on account of the high voltage that they must generate, and the largest size of Brush machine is only of about 76 kilowatts capacity. This machine generates 9.6 amperes at 8,000 volts or 6.6 amperes at 11,000 volts, depending on the winding with which it is provided. These machines, while small compared with most constant-potential dynamos, are considerably larger than the older types of arc machines and have a somewhat higher efficiency. Large machines are almost a necessity in city stations where a large number of lamps must be operated and where floor space is limited.

that the armature will be short-circuited and, hence, will allow current to pass through the fields without running the machine as a motor. On the T. H. machine this can be done by simply closing the armature short-circuiting switch, or field switch, as it is sometimes called. Then connect the positive pole of another machine to the negative pole of the machine to be fixed and allow the current to flow for a few moments. If another machine is not available, a number of cells of battery may be used. This will reverse the polarity and bring the machine back to its former condition. After this is done, the short-circuiting loop may be removed from the brushes. Do not attempt to reverse the polarity while the machine is running.

40. Running Arc Machines in Series.—Sometimes conditions may arise where it is necessary to run two arc machines in series in order to supply the lamps on a given circuit, because the number of lights to be operated may exceed the capacity of any one of the available machines. The two machines are connected in series by connecting the positive terminal of one to the negative terminal of the other, in just the same way as cells of battery are connected together when their E. M. F.'s are to be added. When arc machines are run in this way there is often trouble due to the current seesawing or *hunting*, as it is sometimes called.

The current, instead of remaining steady, surges up and down. This is caused by the unstable action of the regulators on the two machines; both try to do the regulating at once and the result is an unstable condition of affairs. The best thing to do under such circumstances is to throw one regulator out of action and make the machine generate its full-load voltage by blocking the regulator or setting the brushes at their position of maximum E. M. F. This machine will then generate a constant E. M. F., and whatever changes are necessary will be taken care of by the regulator on the other machine.

34. Cleaning and Wiping.—In the first place, the fact must never be lost sight of that series arc dynamos generate a very high pressure, much higher, in fact, than many of the alternators in common use. Cleanliness is essential with all dynamo-electric machinery, but it is especially important in the case of arc machines. All dust and dirt must be kept off them or a short circuit of some kind is bound to occur sooner or later. It will pay any station that operates many of these machines to put in a small air compressor and pipe compressed air around the station, so that the dust and dirt may be blown out. Holes and corners can be reached in this way that would never be touched or that could not be reached otherwise. Although a dynamo may look clean to outside appearances, dirt and copper dust will often accumulate in just those places where it will eventually cause a breakdown and from which it would be dislodged if a stiff air blast were used. The commutator of an arc machine always requires more or less sandpapering, and the copper dust resulting from this is especially liable to give trouble. Wherever terminals are carried through castings by means of bushings, as, for example, on the legs of the T. H. dynamo or where brush-holder studs pass through the rocker-arm, care should be taken to see that the insulating washers are kept clean. It is a good plan to clean them with benzine occasionally and to give them a coat of clean, thick shellac. Machines should, if possible, be wiped and thoroughly cleaned immediately after they are shut down. When the machines are warm, the cleaning is much more effective than after they have cooled down.

35. Brushes and Commutator.—Arc machines always spark more or less. This is especially true of the open-coil machines, i. e., the Brush and T. H. This sparking does not cause as much burning of the commutator and brushes as might at first be expected, because the volume of current is small and the heating and burning effects are also small. If the same amount of sparking occurred on a constant-potential machine d livering a large current, the commutator and brushes would very soon become burned. At the same time, the segments always roughen up to some extent and the commutator should be cleaned. On the T. H. and Brush machines a strip of very fine sandpaper (never emery or crocus cloth) held against the commutator for a minute or two just before the machine is shut down should be sufficient to keep the segments smooth, unless they have been allowed to get in very bad shape. This may be done without removing the b [illegible] ll copper dust should be thoroughly cleaned o [illegible] afterwards. It is often a good plan to put a litt [illegible] commutator, as it generally prevents the cut [illegible] gments. Oil should, however, be used in very [illegible] ties. If too much is used, it will make the comm [illegible] en or it may cause flashing. In working around th [illegible] r of these machines, great care should be taken. [illegible] ne hand, and if it is necessary to wipe off the con [illegible] fasten the cloth on the end of a stick, so that it wil [illegible] ecessary to bring the hand close to the brush holders.

36. Nearly all arc machines use copper brushes. An exception to this is the Western Electric dynamo, which uses graphite or carbon brushes. The T. H. and Brush machines use thin brushes, consisting of one thickness of rolled copper about .03 inch thick. The brush is divided into a number of fingers by longitudinal slits, in order to make it flexible. Brushes of this kind should rest on the commutator tangentially and should be sprung or bent just enough to give a good, firm contact. Gauges for setting the brushes are generally sent with the machines. The copper brushes used on the Wood, Excelsior, Ball, and other machines having closed-coil armatures are made up of a number of leaves of thin, rolled copper (usually from .01 to .015 inch in thickness). These brushes are set at a slight angle to the commutator, so that the end wears down on a bevel. The sparking always burns the ends of the brushes more or less and draws the temper from the copper for a short distance back from the tip. This necessitates clipping off the ends from time to time, so as to keep them straight and smooth. After being clipped, the ends should be smoothed up with a fine file. As these brushes are quite thin and do not carry a heavy current, it is not necessary to file the ends to a bevel to suit the commutator, as must be done with the thick copper brushes used on constant-potential machines.

37. Troubles in Armatures. — The troubles in arc armatures are usually of three kinds: *grounds, short circuits,* and *open circuits.* Grounds are generally caused by the insulation breaking down between the core and one or more of the coils. As it is not usually possible to get at the insulation between the core and the coil, the only remedy is to rewind the defective part. Short circuits are caused either by two commutator bars becoming connected together, by the coil terminals becoming connected, or by a connection being made between the turns of the coil itself. In any event, a short-circuited coil is almost sure to burn out as soon as the machine is started, because the coil with the short circuit forms a closed circuit in itself, and as soon as it begins to cut lines of force, heavy local currents flow in it. An open circuit in a coil will not, of course, cause the coil to burn out, but it will cause bad sparking at the commutator.

On closed-coil armatures, where the number of coils is large, a defective coil may be cut out temporarily without interfering, to any great extent, with the operation of the machine, but it should be renewed at the first opportunity. A coil may be cut out by disconnecting its terminals from the commutator and putting a short piece of wire or a jumper in its place, as indicated in Fig. 18 (*a*) and (*b*). Here *a* is the defective coil connected to the bars in the usual way,

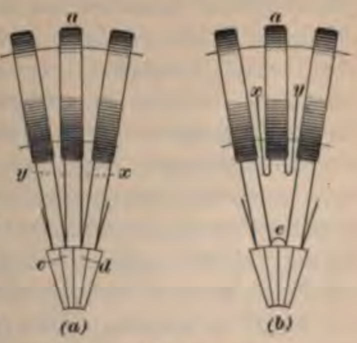


FIG. 18.

been used in comparatively few cases. Instead of supplying the lamps directly from the machine, a considerable range of applied E. M. F. may be obtained by using a constant-potential transformer with its secondary coil split up into a number of sections. The lamps are each provided with a reactance coil, as before, but the use of the transformer admits of a considerable range in the number of lamps that may be operated on a circuit; that is, the combined voltage necessary for the lamps may be considerably different from that generated by the alternator.

45. Operation From Constant-Current Transformers.—The method that has so far been most largely used for the operation of series alternating-current lamps from

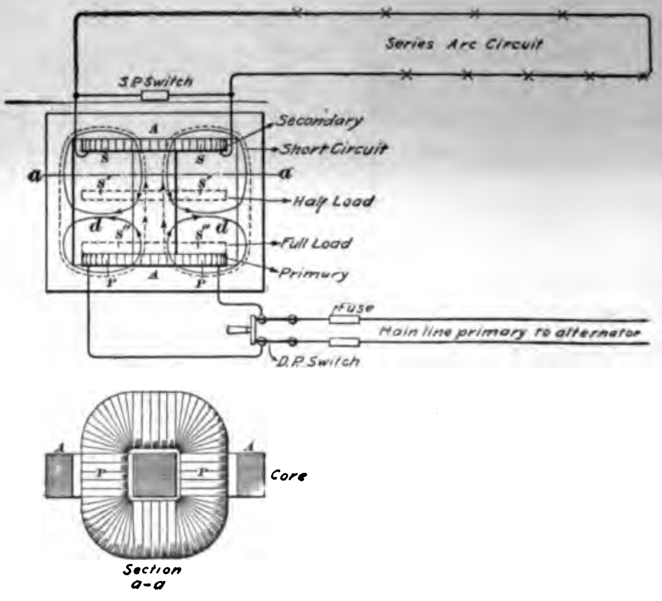


FIG. 21.

constant-potential alternators is that in which a special transformer is used to transform from constant potential to constant current. This means that the transformer must be so constructed that its secondary voltage will change automatically as the number of lamps is changed. Fig. 21 illustrates the action of a transformer of this kind invented by Prof. Elihu Thomson and largely used in connection with series alternating-current lighting.

46. *A A* is a laminated iron core built up in the same way as a core for an ordinary transformer. *P P* is the primary coil wound so as to be thin and flat and surrounding the central part of the core, as shown in the sectional view. This coil is fixed in position and is attached to the lines leading to the alternator that maintains a constant or nearly constant pressure across the terminals of the coil. *S S* is the secondary coil, which is also thin and flat. This coil is free to move up and down. It is suspended from quadrants on the end of a lever and its weight is partially counterbalanced by weights hung on the other end. The terminals of the secondary are connected to the arc line by means of flexible cables that will not interfere with the free movement of the coil.

47. The action of the transformer is as follows: When the arc circuit is open and the primary is connected to the alternator, the secondary occupies the dotted position *S′ S′* resting on the primary. The apparatus will then act like an ordinary transformer; an alternating magnetic flux will be set up through the core, as indicated by the curved dotted lines, and a high E. M. F. will be generated in *S′ S′*, although no current can flow in it because the secondary circuit is open. Let us now take the other extreme case, where the secondary is short-circuited by closing the single-pole switch connected across the arc line. As soon as the switch is closed, a heavy current will flow in the secondary coil and this current will be in the opposite direction to that flowing in the primary. It is a well-known fact that parallel wires carrying currents in opposite directions repel each other, and the result in this case is that the coil is repelled so that it moves up to the other extreme position S S, shown by the full lines. When half the lamps are burning, the repulsion is sufficient to keep it in the mid-position S' S'.

As the secondary is repelled upwards, the E. M. F. generated in it decreases, because the current in the secondary tends to set up magnetism around the core in a direction opposite to that indicated by the dotted curved lines. The result is that lines of force pass across between the coils, as indicated by the full curved lines, and a large number of lines that thread through the primary coil do not pass through the secondary Moreover, the farther the coils are separated, does this leakage become. The result is that when dary reaches the top position S S, very little through it, and hence its E. M. F. becomes ve By properly adjusting the counterbalancing of transformer of this kind can be made to hold in the secondary constant within remarkably cl ough a wide range of load.

48. Fig. 22 shows or larger sizes of these transformers with the case remov Here there are two fixed primary coils P P and P' P' and two movable secondaries S S and S' S'. The two secondaries are counterbalanced against each other by means of the levers, sectors, and chains shown in the figure, so that when the load is light both coils occupy a position near the center, and when it is heavy they both move towards the end coils. The weight w required to counterbalance the repulsion effect is carried by a small auxiliary lever l that projects through the top of the case. The two secondary coils may be connected in series to feed a single circuit, or they may be connected to two circuits, as in the multicircuit Brush dynamo. The whole transformer is placed in a corrugated cast-iron case filled with oil. This secures good insulation and makes the movements of the coils smooth, because the whole moving system acts like a dashpot.

49. Constant-current transformers may be placed either in the station or in a substation at a convenient point near where the lamps are to be supplied. In some instances they have been placed in substations and equipped with automatic time switches that cut them out in the morning as soon as the lights are no longer needed. At light loads, a system of this kind has a poor power factor; but if worked at nearly full load, the power factor is about .8, or about as good as the power factor of a load of induction motors. The low power factor has been urged as an objection against systems of this kind, and while it undoubtedly is an objection, it must not be forgotten that the doing away with arc-light dynamos and running all the lights,

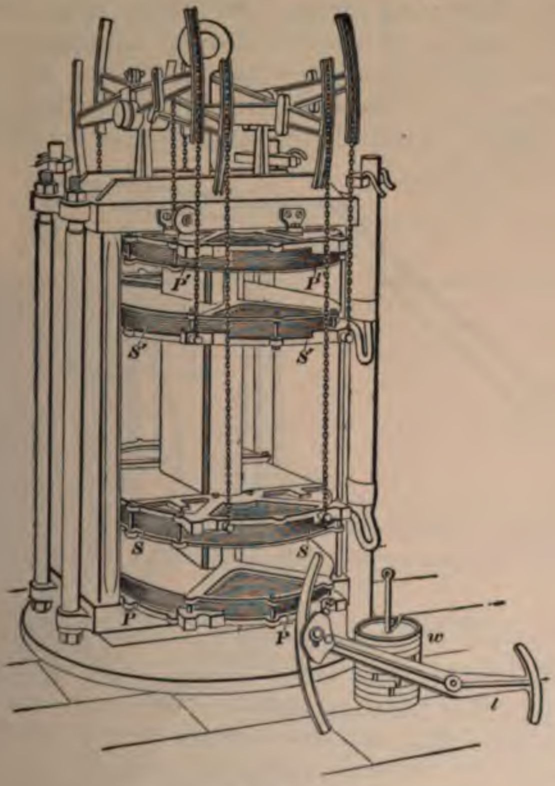


FIG. 22.

both arc and incandescent, from the same kind of alternator is an advantage that goes far to outweigh the disadvantages of a low power factor.

50. Regulation by Means of Variable Reactance.—Fig. 23 shows another style of regulator for the operation of series alternating-current arc lamps from constant-potential circuits. It consists of a coil *C* mounted on the end of a lever and counterbalanced by the weight *W*. The laminated core *D* is ш shaped and the coil slides over the center tongue. When all the lamps are in operation, the coil is balanced so that it is near the top of the core. If lights are cut out, the current tends to increase and the coil is pulled down. This increases the reactance of the coil, and the increased counter E. M. F. generated in it keeps the current down to its proper value. The regulator is connected directly in series with the arc circuit, as indicated in Fig. 24. At *A* the regulator is shown at the

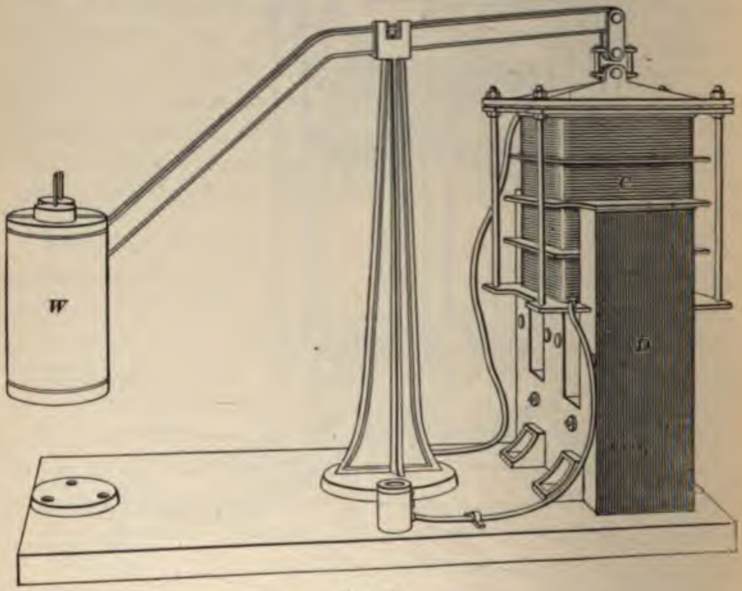


FIG. 23.

station, the terminals of the arc circuit in this case being brought to the plant. At *B* the regulator is shown located at a convenient point out on the line. The terminals of the

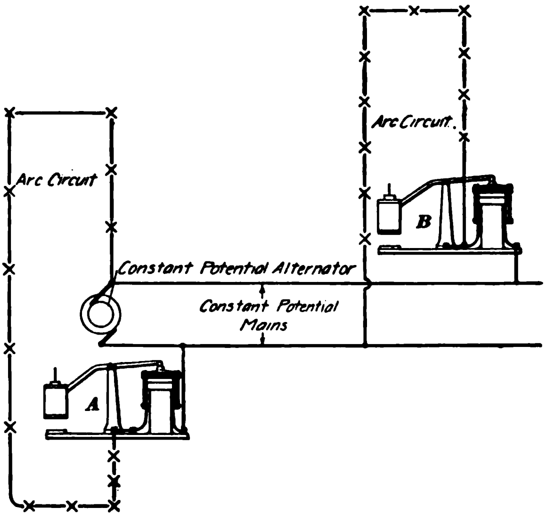


FIG. 24.

circuit are not carried back to the station. By adopting this latter arrangement, a saving in copper can sometimes be effected.

51. From what has been said with regard to lamps, dynamos, and the various systems of operation, it will be seen that there is a wide range of choice in the selection of apparatus. The examples that have been selected have been taken because they are the ones that have, on the whole, been most widely used and serve to bring out the main points connected with the principal systems of operation.

The introduction of the enclosed-arc lamp has changed the methods of arc lighting considerably within recent years and has been responsible for the steadily increasing use of alternating current for this purpose. The alternating-current open-arc lamp stood practically no chance against its rival, the direct-current open arc, but the case is different with the enclosed-arc lamp. It is pretty generally admitted, however, that the alternating-current arc does not give quite as satisfactory all-around service as the direct-current arc; but the difference, at least so far as street lighting is concerned, is not great enough to prevent the introduction of the alternating-current arc for this purpose. In many cases, their use results in a much simpler and cheaper station equipment, which goes a long way to compensate for slight inferiorities in the light-giving qualities of the lamps.

ARC-LIGHT SWI IBOARDS.

GENERAL CONSI ATIONS.

52. Arc-light switchboards bear little resemblance to those used for constant-potential incandescent lighting. In most stations of any size, there are several arc machines and several circuits, and it is desirable to have the switchboard arranged so that any machine may be connected to any circuit. It is also necessary to arrange things so that a circuit may be transferred from one machine to another while in operation, or, if necessary, so that machines or circuits may be operated in series. An arrangement of switches to accomplish this would be exceedingly complicated, and arc-light boards are, therefore, of the plug variety. The various connections are made by inserting plugs into receptacles, the circuit being completed in some cases by flexible cables and in others by the plug itself.

53. Operating Circuits in Series.—Quite frequently, when the number of lamps in one circuit is insufficient to load up a dynamo, two or more circuits are connected in series, at the switchboard, with a single machine. The terminals of the circuits should be marked + and — on the switchboard, the + side being that at which the current leaves the station and the — side that at which it returns. In connecting circuits in series, the — end of one circuit should be connected to the + end of the other, as indicated in Fig. 25. If two — ends are connected, the current will flow through the second circuit in the wrong direction and the lamps will burn "upside down."

The switchboard is usually equipped with an ammeter that will indicate when the current is flowing in the proper direction. Some of these ammeters, for example, the Weston, will not give a deflection over the scale unless the current flows in at the + terminal. Others have an indicating attachment that shows whether the current is flowing the wrong way or not. It goes almost without saying that series arc circuits are never connected in parallel. If this were done, the current would split between the circuits and the lamps would not operate properly. If the circuits are supplied with alternating current, they may be connected in series regardless of their polarity, as both carbons burn nearly alike in alternating-current lamps.

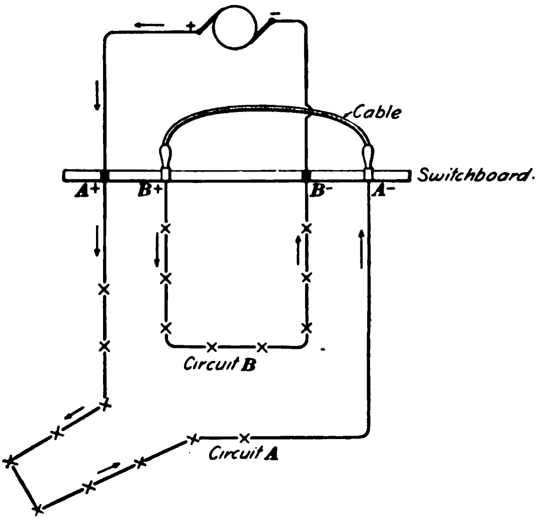


FIG. 25.

N AND OPERATION OF ARC SWITCHBOARDS.

Sin e Board With Cables.—Fig. 26 illustrates t the simplest possible type of board equipped with an neter and terminals for two machines and four circuits. se terminals take the form of sockets or spring jacks mounted on the board, and connections are made between the various receptacles by means of heavily insulated, flexible cables provided with plugs at each end. Each terminal is double, and those for the dynamos are arranged in the lower row and marked +*A*, +*B*, −*B*, each dynamo being distinguished by its letter *A* or *B*. The terminals of the four line circuits are arranged in two rows in the upper part of the board and are marked +*1*, −*1*, +*2*, −*2*, +*3*, −*3*, +*4*, −*4*, each circuit being distinguished by its number *1*, *2*, *3*, or *4*. The ammeter *A M* is mounted in the center of the board and is provided with terminals + and −. The board itself is usually made of a good quality of marble. Slate is not a good material for arc boards, as it is liable to contain metallic veins. It must be

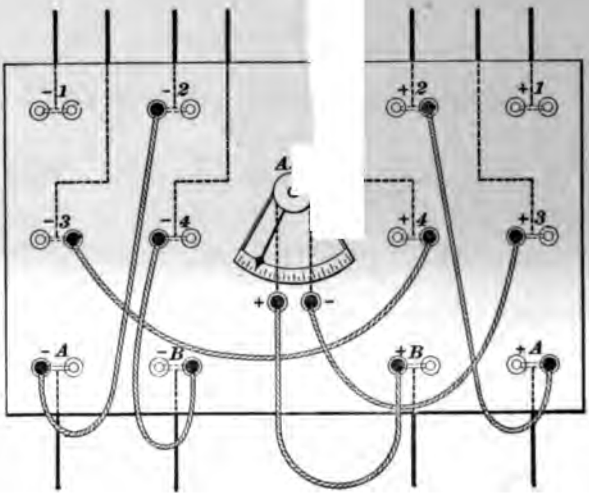


FIG. 26.

remembered that the pressure between the terminals of an arc machine at full load is very high, hence the switchboard terminals must be well insulated. On most of the best boards the terminals are not even allowed to come into contact with the marble, but are insulated from it by means of hard-rubber bushings, the marble being used merely as a support and not depended on for insulation.

55. The operation of plugging in circuits or dynamos is a thing that always appears confusing to the student when an attempt is made to explain the method on paper. It is, however, comparatively easy to follow out on the board itself, where one can handle the cables and plugs and make the required connections for himself. A little practice during the daytime, when the circuits are not in use, will soon enable one to become so familiar with the method of operation that all necessary changes can be made quickly and with certainty.

In making changes on an arc board, it must be distinctly borne in mind that a circuit carrying current should never be broken in order to cut in or out line circuits containing lamps. If the circuit is opened, the effect is to suddenly increase the resistance of the circuit by a large amount, and the voltage will rise greatly. Besides causing a long, vicious arc at the switchboard and perhaps injuring the attendant, it is very hard on the insulation of the dynamo and may be the means of puncturing the insulation on an armature or field coil. If a dynamo or circuit is to be cut out, it should first be short-circuited. Arc machines are not injured by short-circuiting as constant-potential machines would be, because as soon as they are short-circuited the voltage generated drops to a very small amount. In Fig. 26, each terminal is made double, so that transfers may be made without opening the circuit.

In Fig. 26, circuit *1* is "dead," because its terminals are not connected to anything. Circuit *2* is on dynamo *A*, the path of the current being $+A - +2 - -2 - -A$. Circuits *3* and *4* are in series with each other on dynamo *B*, and the ammeter is also in series in this circuit. The path of the current is $+B$, through the ammeter to $+3 - -3 - +4 - -4 - -B$.

56. Suppose that it is desired to connect the ammeter in circuit *2*. To disconnect it from circuits *3* and *4*, it is first short-circuited by plugging in a cable across the terminals $+B$ and $+3$. The two plugs on the cables leading to the ammeter may then be withdrawn from $+3$ and $+B$, and the circuit will not be opened. The plugs removed from $+B$ and $+3$ may then be inserted at $+A$ and $+2$, respectively, thus shunting the ammeter across the cable $+A$ $+2$. The cable $+A$ $+2$ is then removed and the current supplied to circuit *2* passes through the ammeter.

57. Again, with the connections as shown in Fig. 26, suppose that it is desired to connect circuit *1* in series with circuit *2* without shutting down either the dynamo or circuit *2*. The first step will be to connect terminal -1 with terminal $+2$, then terminal $+A$ with terminal $+1$. The cable directly connecting terminal $+A$ and $+2$ may now be removed without opening the circuit at any point and at the same time throwing the two circuits *1* and *2* in series.

58. Board Without Cables.—Where a large number of machines and circuits are operated, the number of cables hanging around the front of the board becomes so great that they are in the way when transfers are being made. In order to overcome this objection, boards have been devised that do away with cables almost entirely. Some very large boards have been made on this plan. At present, the use of large multicircuit machines has resulted in a reduction of the number of dynamos needed for any one station, and there seems to be a tendency to go back to the style of board using cables. The simple cable board is no doubt cheaper than the other type and if properly built will give excellent service. Moreover, with the cable type of board the attendant can see at a glance just what connections he has made.

59. Fig. 27 illustrates the principle of one type of board made by the General Electric Company, in which cables are almost wholly dispensed with. This is accomplished by means of two groups of contacts arranged in two parallel planes a little distance apart. The contacts in the front group are divided into pairs of horizontal rows, each pair being connected to the terminals of one of the dynamos. The contacts on the back group are divided into pairs of vertical rows, each pair being connected to one of the circuits. The contacts, which are in the form of split bushings, are directly opposite each other and the connection between any dynamo and any circuit is made by a long brass plug that is pushed through the outside contact to the inside. The arrangement will be clear by referring to Fig. 27. The dynamo terminals are lettered *A*+, *A*−, etc. and the circuit terminals *1*+, *1*−, as in the preceding case. The back or *circuit* board is provided with an extra row of contacts at the bottom, by means of which circuits may be connected in series, using for the purpose cables having suitable terminals, similar to those used for connections

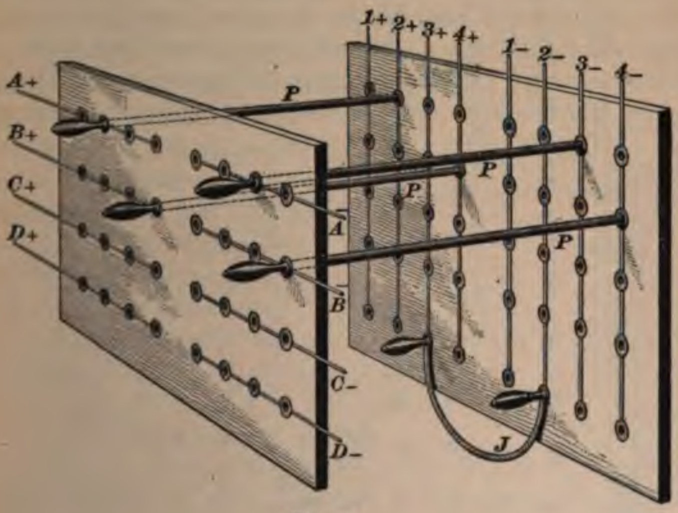


FIG. 27.

in the form of board first described. In Fig. 27, the path of the current is as follows: $A+-2+-2--1-3+-3-A-$. Circuits *2* and *3* are in series on dynamo *A*. Also, we have circuit *4* on *B* because $B+$ and $B-$ are plugged through to $4+$ and $4-$. Circuit *1* is dead. By using a cable with short plugs that only reach through the front bushings, dynamos may be connected in series, if necessary.

60. In Fig. 27 the sets of bushings are shown separated much farther than they are on the actual board, in order to make the figure clear. On the actual board the back contacts are carried on vertical copper straps that are attached to the front board. Fig. 28 shows the general appearance of one of these boards and indicates the location of the positive and negative terminals of the dynamos and circuits. Fig. 29 gives an idea as to the method of mounting the bushings and is self-explanatory. Bushings *b* are the ones used for connecting circuits in series. The board shown

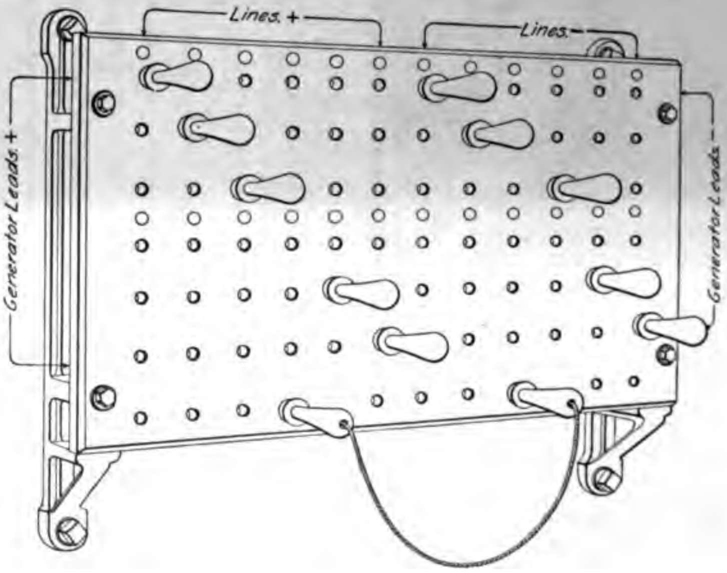


FIG. 28.

in Fig. 28 has no ammeter; on some of the larger boards it is customary to connect an ammeter permanently in each circuit. In such cases they are usually mounted on a separate marble slab placed above the one carrying the contacts. The board shown in Fig. 28 is designed for six dynamos and six circuits.

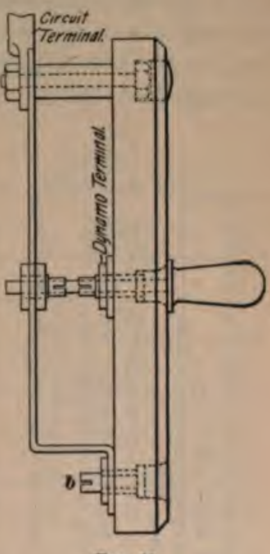
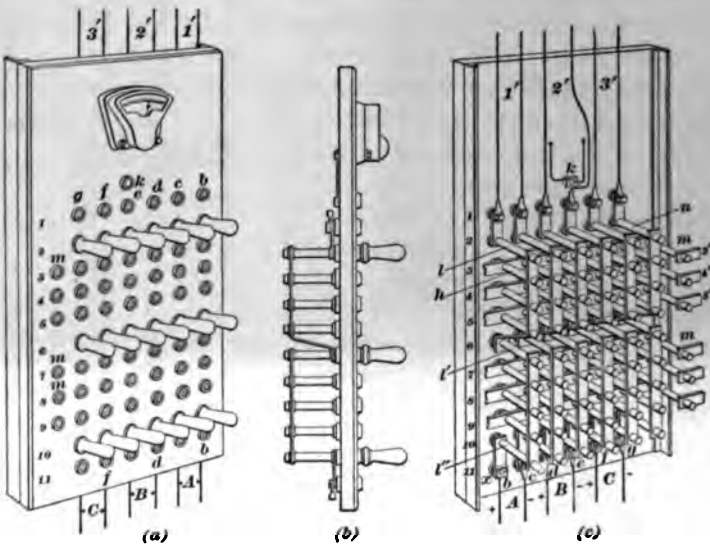


FIG. 29.

61. Panel Type Board. — This board is somewhat similar to the one last described. It is, however, designed so that it may be built up in panels in a manner similar to that described for incandescent-lighting boards, so that as more dynamos and circuits are needed the board may be extended by adding more panels. The general arrangement of the board will be understood by referring to Fig. 30 (*a*), (*b*), and (*c*). Referring to Fig. 30 (*c*), the lower terminals *b*, *c*, *d*, *e*, *f*, *g* are connected to the machines *A*, *B*, and *C*. The terminals at the top connect to the circuits *1'*, *2'*, and *3'*. The crosspieces *3*, *4*, *5*, *7*, *8*, and *9* run across the back of the board and may be connected to similar crosspieces on the next panel by means of the connection strips *3"*, *4"*, *5"*, etc. and plugs inserted in the side sockets *m*, *m*. An ammeter jack is connected in one side of each of the machines at the points *b*, *d*, and *f*, Fig. 30 (*a*). An ammeter cable that consists of two wires connected to a double contact plug on each end is provided. One plug is inserted into the ammeter jack at *b*, *d*, or *f* and the other end into jack *k*, thus connecting the ammeter in series with any one of the three dynamos.

Inserting the ammeter plug in the jack at *b*, for example, simply cuts the ammeter into circuit. When the plug is withdrawn, the jack closes the circuit before the plug is fully drawn out, so that the circuit is not interrupted. The tubular supports n, shown in Fig. 30 (c), are of insulating material, and the plugs pass through them to make contact with the vertical strips. It will be noticed that there are three breaks in each vertical strip between a dynamo terminal and a corresponding circuit terminal. These breaks are at l, l', l''. When, therefore, these breaks are plugged across, as indicated by the three rows of plugs in Fig. 30 (a),



(a) (b) (c)

FIG. 30.

dynamo A is operating circuit $1'$; dynamo B, circuit $2'$; dynamo C, circuit $3'$. This will be apparent by referring to Fig. 31. The vertical lines here represent the vertical bars, in which the breaks are indicated by open spaces. The black circles represent the plugs, and are supposed to connect the two terminals between which they are inserted. Fig. 30 represents the ordinary condition of running, and it will be noticed that the cross-bars are not in use.

62. Suppose that it is desired to shut down machine B and run circuits $1'$ and $2'$ in series on machine A. Insert plugs at c_5, d_5, c_7, and d_7 and remove plugs c_6 and d_6. This leaves two circuits and two machines in series. Short-circuit machine *2* by inserting a plug at e_7. Then cut out machine *2* by removing plugs d_{10} and e_{10}. Then take out plug d_7, and the board will be as indicated in Fig. 32. The path of the current will now be $A+-b_{10}-b_6-b_2-1'+$ through circuit $1'-1'--c_2-c_5-d_5-d_2-2'+$ through circuit $2'-2'--e_2-e_6-e_7-c_7-c_{10}-A-$ and circuits $1'$ and $2'$ are in series on dynamo A.

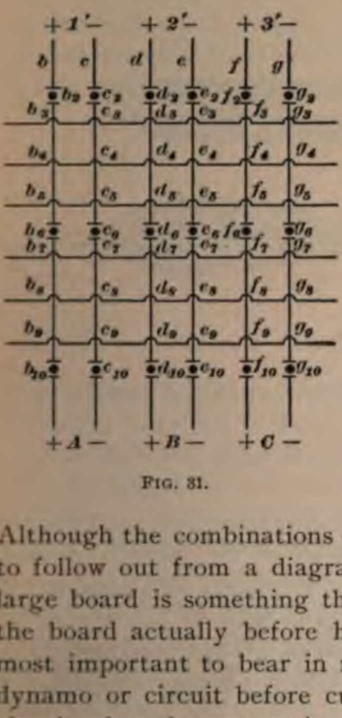


FIG. 31.

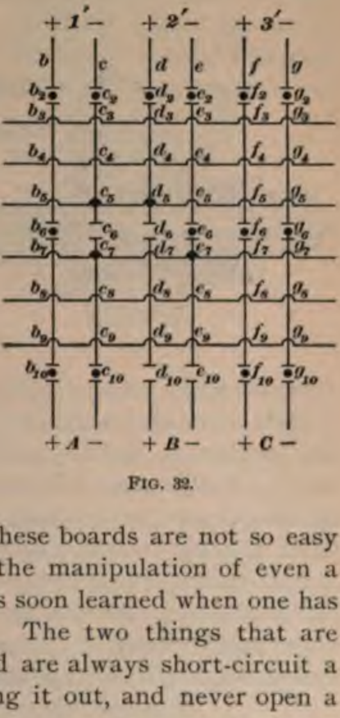


FIG. 32.

Although the combinations on these boards are not so easy to follow out from a diagram, the manipulation of even a large board is something that is soon learned when one has the board actually before him. The two things that are most important to bear in mind are always short-circuit a dynamo or circuit before cutting it out, and never open a circuit when the current is on.

63. Brush Plug and Spring Jack.—As stated above, in some of the boards used with large multicircuit machines, the ordinary cable method of connection is used. Another feature of modern arc boards is that no live metal parts are allowed on the surface where they might happen to be touched by the attendant. These precautions are especially necessary for boards that are used with large arc machines, some of which generate 10,000 or 11,000 volts.

Fig. 33 illustrates the style of plug used on Brush arc boards. It will be noticed that pains are taken to secure high insulation. *A* is the marble panel and *b* the metal plug, or contact, attached to the cable as shown. *C* is a cup-shaped casting to which the line is connected and into which *b* slides and is held, so as to make a good contact by the spring clip *s*. *C* screws on to the end of the hard-rubber bushing *D* and is separated from the marble by the insulating washer *E*. *F* is a hard-rubber sleeve, or tube, and *G*

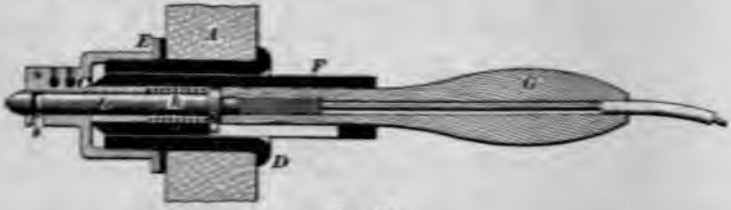


FIG. 33.

a maple handle; *h* is a spiral spring that causes the sleeve *F* to slide over the contact piece *b* when the plug is pulled out, so that by the time the plug is pulled entirely out of the board, the contact *b* is completely covered and there is no danger of the attendant coming into contact with it. When a plug is inserted, the nose of the sleeve *F* comes against casting *C*, and as the plug is pushed on in, contact *b* passes through the hole in *C* and is held by the spring *s*. These jacks are usually mounted in pairs connected together, so that transfers may be made without opening the circuit.

64. Western Electric Plug and Jack.—Fig. 34 shows an improved form of jack and plug that is used by the Western Electric Company. It consists of a main jack *A* and two smaller jacks *B*, *B*, which are used in making transfers. The springs *a*, *b*, *b* hold the plugs in place by engaging the groove on the end of the plug. This plug also has a hard rubber sleeve *c* that slides over the metallic terminal *d* as soon as the plug is pulled out. The general arrangement of the plug and jack will be apparent without further explanation.

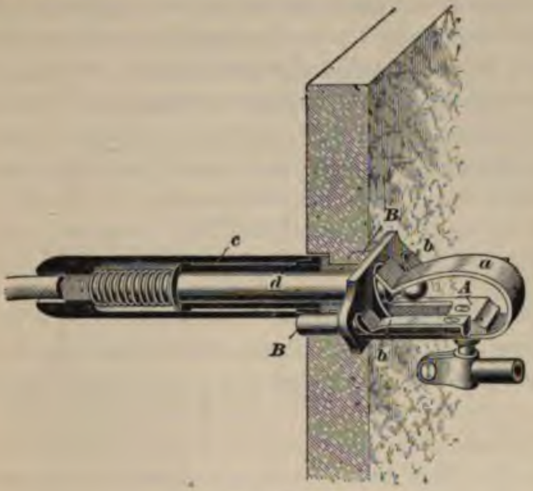
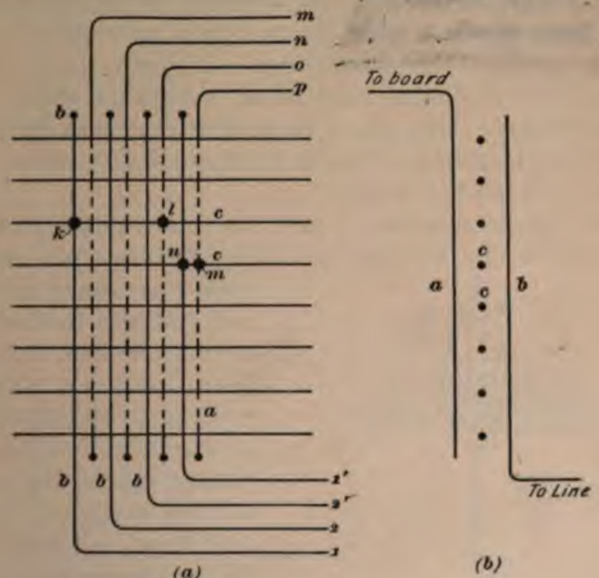


FIG. 34.

65. Ammeters.—An arc board requires comparatively little auxiliary apparatus. A single ammeter is about all that some boards are provided with, but others, equipped on a more elaborate scale, are provided with an ammeter for each machine. This ammeter is in general the same as those used for ordinary work except that its scale reads only to 10 or 15 amperes, the current for series lamps usually being from 6 to 10 amperes. The ammeter is always connected in circuit in the same manner as an arc lamp. Sometimes it is left in circuit all the time, but more often it is only cut in occasionally to find out if the current is right.

66. Voltmeter.—It is now common practice to equip arc boards with a high-reading voltmeter. This may be mounted in any convenient position and should be provided with flexible cables having well insulated terminals, so that the voltmeter may be connected across any circuit or dynamo. The voltmeter should have a range at least as high as the straight and free from crossings as possible. A number of fires have resulted from the numerous crossings and the general maze of wires to be found in some of the older stations, especially at the point or in the tower where the wires enter the building. These crossings were generally made in order to bring the wires to the switchboard in the correct order for connecting up. In the best stations, it is now usual to have, in addition to the switchboard, a **transfer board,** the object of which is to enable the lines running to the switchboard to be connected to any of the lines running out of the station. By using a transfer board, the wires coming into the station may be brought in in any order that may be most convenient, and they may be run straight to the board without crossings. They may then be sorted out and connected to any desired circuit terminals on the switchboard by using the transfer board. The transfer board is also very useful for changing the terminals of a circuit from one part of the board to another, as it enables



(a) (b)

FIG. 35.

it to be done without disturbing the connections at the switchboard terminals themselves.

The general arrangement of the transfer board will be understood by referring to Fig. 35. A number of vertical wires *a* and *b* are stretched on a substantial framework. These wires are usually about No. 4 or 6 B. & S. and are bare. They are separated from 5 to 6 inches and are directly opposite one another, although in Fig. 35 (*a*) they have been shown a little to one side of each other in order not to confuse the connections. Between these vertical wires a corresponding number of horizontal wires *c* are also stretched. One set of vertical wires *a* runs directly to the circuit terminals on the switchboard and the other set *b* connects to the line wires.

The horizontal wires are used for connecting across from any line to any switchboard lead. For example, suppose *1* and *1'* are the terminals of a circuit and that we wish to connect them to switchboard leads *o*, *p*. By connecting to the cross-wire, as shown at *k*, *l*, line *1* is connected to *o*, and by connecting as shown at *m*, *n* line *1'* is connected to *p*. By this arrangement, therefore, the line and switchboard connections may be transferred in any way desired. The actual number of wires used in any case will, of course, correspond to the number of circuits to be accommodated. The connections between vertical and horizontal wires are usually made by means of a clamp

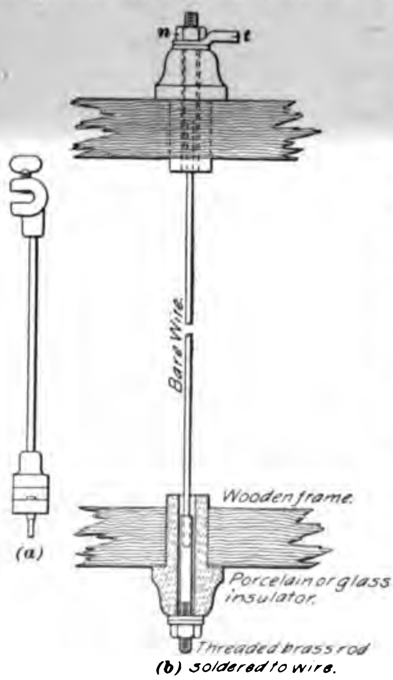


FIG. 36.

connector, somewhat similar to that shown in Fig. 36 (*a*). Different methods are used for stretching the wires on the frame, but they should always be mounted so that they will be thoroughly insulated. On this account the wire should be passed through porcelain or glass insulators at each end, as indicated in Fig. 36 (*b*). The wires are stretched tightly by screwing up on the nut *n* and the line wire attaches to terminal *t*.

INTERIOR WIRING.

(PART 1.)

PRELIMINARY CONSIDERATIONS.

1. In the work of every artisan there are certain factors that must never be overlooked and certain conditions that must always be fulfilled before the final object of the work can be reached or even approached.

In electric wiring, the ultimate object is the conveying of the electricity to the lamp, bell, motor, or other device that is to be operated. But this must be done in a proper manner; otherwise danger, unsatisfactory operation, and waste are sure to result.

2. There are four things that should be considered in every electric installation. They are (*a*) safety, (*b*) satisfactory operation, (*c*) convenience and neatness, and (*d*) economy. The first of these considerations is by far the most important in all ordinary wiring. Therefore, the electrical artisan should understand, first of all, what are the sources of danger in the use of electric currents and then what precautions are necessary and what conditions must be complied with to avoid these dangers. When he thoroughly understands these things, he should learn how to make his work satisfactory in other respects and profitable to himself.

The same causes that, under certain conditions, make electricity dangerous to life also make it a source of fire hazard. There are also conditions under which an electric

For notice of copyright, see page immediately following the title page.

current may cause fire, although it may not be directly dangerous to life. In discussing the precautions necessary to avoid any chance of fire from an electrical cause, the student will learn how to avoid danger to life as well, so that it is unnecessary to discuss that subject by itself.

FIRES CAUSED BY ELECTRIC WIRING.

3. The so-called "electrical fires" or fires that are caused by the presence ef electric wires or apparatus within a building can be divided into three classes, as follows:

(*a*) Fires caused by poor work or improper materials.

(*b*) Fires caused by overloading the apparatus or wire with a higher voltage or with more current than it was designed to carry.

(*c*) Fires caused by lightning striking the outside lines or by the crossing of circuits that should never come into contact with one another.

A good job of interior wiring overcomes all danger due to the first two of these sources of hazard and most of the danger due to the third, but not all, for accidents sometimes occur outside of the buildings, against the results of which the present accepted devices for the protection of inside circuits are not sufficient. The failure of a lighting company to use proper lightning arresters and transformers or to properly insulate the outside wires may cause trouble within a building where the wiring is properly done.

THE NATIONAL ELECTRICAL CODE.

4. When electric lights first came into general use, the insurance companies discovered that there were many fires of electrical origin, the wiring done on the first installations being of very inferior workmanship. The various associations of underwriters, therefore, formulated rules in accordance with which they required that all wiring be done or they would not insure buildings containing it. In the course of time, these various rules of local associations were reduced to a uniform code, and finally, in 1898, they became known as the **National Electrical Code** and received the endorsement of practically all the inspection bureaus throughout the United States, besides that of the following organizations: the American Institute of Architects, the American Institute of Electrical Engineers, the American Society of Mechanical Engineers, the American Street Railway Association, the Factory Mutual Fire Insurance Companies, the National Association of Fire Engineers, the National Board of Fire Underwriters, the National Electric Light Association, the Underwriters' National Electric Association.

A few cities have rules of their own that differ slightly from this code, but the differences are not vital. Any person doing work in any city where there is municipal legislation governing his work should investigate the laws of that particular place before undertaking to lay out work for himself. Every wireman should be supplied with a copy of the latest edition of the National Electrical Code and do work in compliance with those rules, whether additional laws exist or not. Copies of the code and of all other information published by the Underwriters Association for the sake of reducing the fire hazard can be obtained by writing to the laboratories of the National Board of Fire Underwriters at Chicago or by applying at the nearest Underwriters' Inspection Bureau. The rules are revised by conventions as often as changes in the electrical art make such revision necessary.

5. In addition to this code of rules, the National Board of Underwriters publishes each year a **List of Approved Fittings** for use in connection with the code. This list contains the names of articles that have been found entirely satisfactory, together with the names of the manufacturers. It does not contain a list of *all* fittings that will pass inspection, and many good articles are not listed in its pages.

either by sparking at the commutator or from heating effect of the lamps.

8. Sparks from an arc lamp dropped on a table underneath that was covered with open boxes of shirt waists. The table and contents destroyed, otherwise no considerable damage.

9. Flexible lamp cord wound around a gas fixture having a soft rubber insulating joint. The current grounded through the joint and the arc ignited the escaping gas.

10. Overheating of No. 14 B. & S. wires due to partial short circuit, caused by moisture, through porous crockery knobs on which wires were mounted. The fuses, which were too large, did not melt for some time and the burning insulation of the wires set fire to combustible material near, causing a loss of $15,000.

11. A fuse block, improperly constructed and placed in close proximity to woodwork, held an arc after a short circuit long enough to set fire to the woodwork.

12. Main feed-wires placed in an elevator shaft were short-circuited by a breakdown of their insulation. A heavy arc was established that set fire to building.

13. Overheating of resistance coil of arc lamp that was improperly insulated and too near adjacent woodwork set fire to building.

14. Short circuit of No. 14 wires installed, contrary to rules, in molding in a place exposed to moisture. The fire was stubborn and burned fitfully between floors and was not extinguished before a loss of $2,000 had been sustained.

15. Fire in public institution. Building wired throughout with weather-proof wire run through joists without bushings, both wires of the circuit being brought through one hole at lamp outlet without separation. Short circuit occurred in attic that quickly set fire to dry timbers.

16. An Edison plug cut-out was improperly used to protect a 5-horsepower motor operating at a difference of potential of 220 volts. Fuse in blowing failed to open circuit, thus maintaining an arc that set fire to building.

17. Circuit controlling an electric flat iron was left turned on, becoming overheated and setting fire to the table. Circuit had no signal lamp or other indicating device recommended for such equipment.

18. Overheating of mechanism in a 2,000-candlepower series-arc lamp, the metal casing of which did not fit, set fire to the ceiling. The store was closed, but the lamp had been left burning until the circuit was shut off. This fire illustrates the advisability of cutting all current out of buildings when the same are unoccupied.

19. A fire occurred in show window, caused by a bath towel falling from support on to a lighted incandescent lamp in bottom of window; the towel becoming ignited set fire to the contents of window and damaged some of the stock in store.

20. Lightning entered building over badly installed watchman circuit. No protective devices at entrance to building. Wires badly insulated, fastened by staples. Heat of wires set fire to joists of building.

21. Ground of 110-volt circuit on gas pipe in attic. Arc burned $\frac{1}{4}$-inch hole in pipe and set fire to escaping gas.

22. Fire in basement of building caused by accumulation of sodium salt on back of three-wire molding run on brick wall. Trouble occurred at a point where a nail had been driven through molding into wall.

23. Short circuit in fixture canopy ignited ceiling above fixture. Fire also occurred at same moment in cabinet at center of distribution. It was found on inspection that the branch cut-out contained copper wire.

24. An ignorant workman installed a lighting circuit in lead-covered cable, fastening same to iron ceiling with staples. Breakdown of insulation of cable set fire to ceiling, when it was found that no main switch had been installed and current could not, therefore, be cut off.

25. Switch on electric-light circuit was mounted in dry-goods store at a point where draperies came in contact

with it. Flash from same ignited draperies and fire spread rapidly to millinery and other inflammable material.

26. Breakdown of insulation on wires of lighting circuit in a fine residence set fire to woodwork inside partitions. Fire occurred at night, and owing to delay in sending in alarm and the distance from fire-department headquarters, fire was not extinguished until a heavy loss had been sustained.

27. Electric-light wire sagged and made contact with telephone wire running to cable box. Box and cable connections completely destroyed.

28. Burglar-alarm, electric-bell, and electric-light wires came together inside the partitions of a residence. The insulation on the wires was ignited and followed up the partitions. Owing probably to lack of oxygen, fire did not break out of partitions, but spread so generally over the house inside that much damage had to be done before it could be extinguished.

29. Circuits were run in circular loom tubing immediately over a steel ceiling. Where the tubing came through the ceiling for a loop, the sharp edges of the ceiling cut through the same, short-circuiting the wires. Arc ignited the insulation of the wires, fire following same up under the ceiling.

30. Fire in livery stable due to blowing of fuse in uncovered cut-out into straw. Fire spread so rapidly that it was impossible for the department to control it.

31. Fire in basement of hotel caused by water leaking and running down the blades of a switch on 500-volt circuit.

32. Serious burn-out of fire-alarm system by cross on 500-volt feed wires of an electric railroad. Nine fire-alarm boxes, a tapper, and an indicator were burned out, the repeater also being partially destroyed. Fire was also started in the residence of the chief of the fire department, but was promptly extinguished. It was found on inspection that the instruments were protected by fuses that were much too short.

7. Figs. 1 to 6 illustrate some characteristic burn-outs; they have been drawn from photographs of burn-outs that have actually occurred.

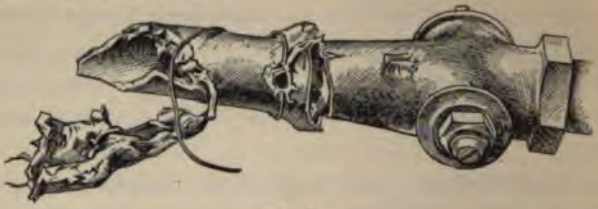


FIG. 1.

Fig. 1 shows a gas pipe that was melted by an arc caused by a heavy current-carrying circuit crossing a signal circuit that was connected to the pipe. The connection to the pipe was poor and unsoldered.

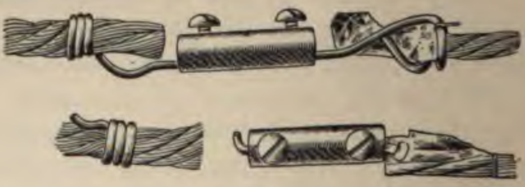


FIG. 2.

Fig. 2 shows joints made with No. 10 wire on a circuit designed to carry 200 amperes. The use of such a poor joint gave rise to heating that resulted in the burning out of the wire.

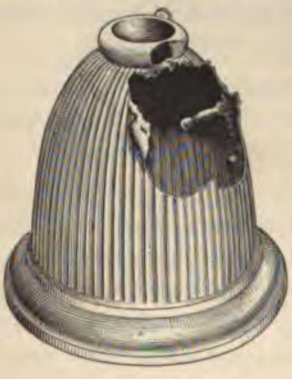


FIG. 3.

Fig. 3 shows a fixture canopy with a hole melted through it, caused by a fixture cut-out inside the canopy becoming short-circuited.

Fig. 4 shows a burn-out caused by a short circuit between weather-proof wires used in molding. Wire with weather-proof insulation only should never be used in molding, and its use in molding is prohibited by the Underwriters. Figs. 3 and 4 are from photographs by Mr. Wm. T. Benallack.

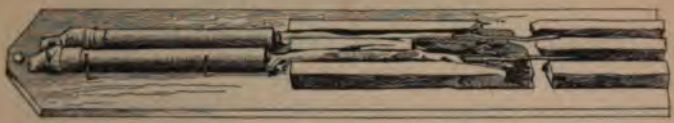


FIG. 4.

Figs. 5 and 6 show burn-outs caused by short circuits in cut-outs. The burn-out in Fig. 5 was due to defective design, the two sides of the circuit being brought so close together that when a fuse melted the arc held over and destroyed the cut-out.

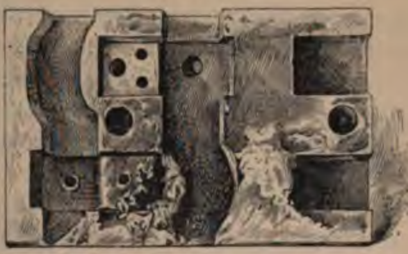


FIG. 5.

In Fig. 6, the cut-out was placed horizontally. When the fuse melted, the metal ran down and established connection between the lines, thus resulting in a short circuit.

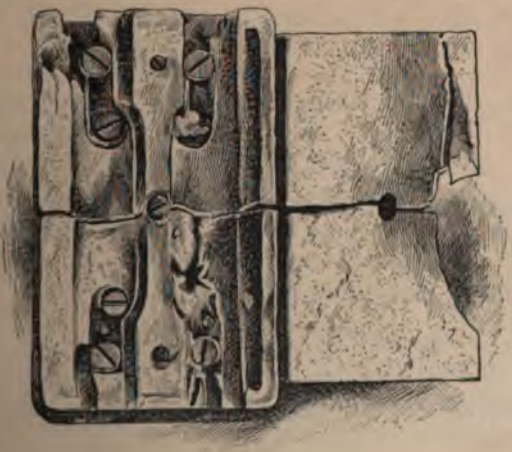


FIG. 6.

ELECTRIC LAMPS.

INCANDESCENT LAMPS.

8. Before taking up the subject of wiring for electric lights, it will be well to look briefly at some of the characteristics of the lamps to which the wiring is to supply current, as the requirements of the lamps have a considerable influence on the character of the wiring. **Incandescent lamps** are the ones mostly used for interior illumination, so we will briefly consider a few of their characteristics. The selection of good lamps of proper voltage, candlepower, and efficiency to suit the work for which they are to be used is a matter of great importance.

The light-giving part or **filament** of an incandescent lamp is of carbon, being generally made of carbonized cellulose thread. Its manufacture has been the subject of much research by the large manufacturing companies, which keep the details as secret as possible. A good lamp filament must be uniform in cross-section, density, and resistance per unit of length. It must also be manufactured with special reference to the voltage and current with which it is to be used.

9. The filament is mounted on the ends of **leading-in wires** of platinum, which pass through a glass neck or stopper. The outer ends of these platinum wires are soldered to copper wires that are connected to the proper parts of the lamp **base** when all the other work on the lamp is finished. The shell of the lamp base is filled with plaster of Paris, which holds the lamp firmly in place.

10. The connecting of the filament to the leading-in wires is usually done with a carbon paste and is an important operation, for the lamps and filaments frequently break at this point.

11. The lamp **globe** surrounds the filament and is airtight. All the air within it is exhausted to a very high degree. The exhaustion is important in all lamps and must be done with extra care for high-voltage lamps, or the current will "arc" across the ends of the leading-in wires and destroy the lamp.

12. Even the highest grades of incandescent lamps are not very long-lived. They may burn for years without having the filament break, but they will not burn at their proper efficiency or candlepower. The light is produced by the carbon being heated to a very high temperature. No known solid substance can be maintained at a temperature of very brilliant incandescence without undergoing a change in its physical properties. This is true of carbon, as of all other materials. The heat alters its density, resistance, and other properties. The higher the temperature, the more rapid is the physical change. Some of the properties lost by heating to high temperatures are regained upon cooling, but others are not. Among the limitations to carbon incandescent-lamp filaments, those in regard to size are very important. Below a certain minimum diameter and above a certain maximum carbon filaments are not practicable.

13. When an incandescent-lamp filament is heated beyond a certain limit, it rapidly deteriorates, giving off gaseous particles that condense on the globe and blacken it. If the heating is very sudden, the filament explodes and may break the glass.

Carbon being highly inflammable when very hot, the air must be exhausted from the lamps. But if only the oxygen were removed, the student may suggest, the lamps would burn satisfactorily. It is true that in that case the filaments would not burn, but the gas within the lamp would become very hot and expand and burst the globe; or if the globe did not break, it would become as hot as the gas within it. Incandescent lamps with the air only partially exhausted are not practical devices, though many have tried to make such.

14. In incandescent-lamp practice, it has been found by experience that the best results are obtained when lamps are

. a certain temperature for about seven hundred urs. They may be burned at a lower temperature for a nger time, but give less light; or at a higher temperature a short time, giving more light. It is very poor economy burn lamps after they have become dim, for they take about as much current as new lamps and give very little light in return. What is wanted is the most light for the least money, taking into account both the cost of current and the cost of renewing lamps.

The effect on a lamp of altering the voltage only a slight amount is much greater th ommonly supposed. By a study of Table I, which is ı by the General Electric

TAI I.

EFFECTS OF CHAN IN VOLTAGE IN STANDARD 3.ı ATT LAMP.

Voltage. Per Cent. of Normal.	Candlepower. Per Cent. of Normal.	Watts Per Candlepower.	Life. Per Cent. of Normal.	Deterioration. Per Cent. of Normal.
90	54	4.63	941	11
91	58	4.41	716	14
92	62	4.21	555	18
93	66	4.04	435	23
94	70.5	3.89	345	29
95	75	3.74	275	36
96	80	3.59	220	45
97	85	3.46	179	56
98	90	3.33	146	69
99	95	3.21	121	83
100	100	3.10	100	100
101	106	3.00	82	122
102	112	2.91	68	147
103	118	2.82		179

Company, it will be seen that at the prices for which lamps sell (about 18 to 25 cents each for a 16-candlepower lamp) it is not economical to burn lamps more than their proper life, and it is of the utmost importance that the voltage be uniform and correct. If the voltage be absolutely steady, lamps may advantageously be burned a volt above their marked voltage and used a correspondingly shorter time. But the advantage is doubtful unless the greatest care is exercised in renewing lamps. The table shows that, for the lamps tested, an increase of 3 per cent. in voltage increases the light 18 per cent., but increases the deterioration 79 per cent. On the other hand, with a voltage 10 per cent. lower, the light is cut about in half, but the life is extended indefinitely. It is to the manufacturer's interest to mark lamps at the most suitable voltage, but poor lamps are often improperly marked, causing a waste both of current and lamps when they are connected in the sockets. Some manufacturers do this false marking to dispose of lamps of odd voltages for which they have no market. "Job lots" are apt to be of this kind, as are all lamps not marked with the manufacturer's name.

15. Incandescent lamps are made of different efficiencies. The most efficient ones should be used where absolutely constant potential is employed, the less efficient ones where the voltage is somewhat unsteady. Fifty- to 125-volt lamps are made to consume from 3.1 to 5 watts per candlepower, according to the grade and the size of the lamp. Good 200- to 250-volt lamps consume about 4 watts per candlepower. Up to the present time it has been found impracticable to make high-voltage lamps more efficient, owing to the fineness and the length of the filament and other difficulties that rapidly increase when the voltage is increased. Generally speaking, the lower the voltage the easier is the manufacture of filaments.

16. Good lamps, when the glass is clean and when they are placed so that the light can freely leave them, do not get very warm; but if something be placed against the

ARC LAMPS.

20. **Arc lamps** are now used much more extensively interior illumination than they were a few years ago. s is due to improvements in the lamps that make them much better suited to this class of work. Arc lamps used on interior work are usually operated in multiple in the same way as incandescent lamps. For many years **open-arc lamps** (i. e., those with the arc exposed to the air) were operated on 110-volt circuits by operating two of them in series across the lines. A small amount of resistance was used in series with these lan improve the regulation and to take up the voltage ove d above that required by the two arcs. Forty or 45 vol ere consumed at the arcs and 20 to 30 volts in the resist e, and the lamps usually required about 10 amperes. since 1895, **enclosed-arc lamps** have come into very e nsive use, displacing the old, low-tension, open-arc la almost altogether and taking the place of clusters of ndescent lamps, and also, to a very great extent, of series- c lamps used in interior lighting.

It was found that by using purer carbons than had been the practice formerly and by enclosing the arc in a small globe, so that free air could not reach it to burn the carbons rapidly, as in the open arc, the voltage at the arc could be increased to 70, 80, or 90 volts and the current reduced to 4 or 5 amperes.

21. In open arcs, the light is produced almost entirely on the positive, or upper, carbon surface, and the combustion of the carbon vapor produced at the arc is essential to the operation of the lamp. In enclosed arcs, a large amount of light is produced in the arc itself, which is from ½ to ¾ inch long.

Not only is it possible to produce these long, high-voltage arcs, but it is necessary to have an arc of at least 70 volts, if it is well enclosed. Shorter enclosed arcs decompose the carbon of the positive pole and deposit it in the form of lampblack on the negative one, thus obscuring the light altogether.

In an enclosed-arc lamp only the highest grades of carbons can be used. Cheap carbons cause flickerings and very rapidly discolor the glass enclosing globe, but the lamps burn from 100 to 150 hours (according to the current used, about 150 hours on 4 amperes), thus being more economical in the use of carbons than open arcs of the same watt capacity, which burn the same amount of carbon in 8 or 10 hours. The light from the enclosed arc is much softer and steadier than that from the old style open arc and has come to be generally considered the proper light for general interior lighting in large establishments and public buildings.

22. The long arc gives a large percentage of violet-colored rays that are not pleasing to the eye and which add very little to the illumination. The inner and outer globes of these lamps should have a slight "alabaster" coloring, which destroys the disagreeable rays. But it must be a very slight coloring, or it will absorb too much good light as well. Opalescent globes should not be used with arc lamps. They increase rather than diminish the objectionable qualities of the light and make the lamp appear to be burning more unsteadily than is actually the case.

23. Satisfactory enclosed-arc lamps are produced for alternating currents. The earlier alternating-current arc lamps were very objectionable on account of the noise produced—a continual, penetrating hum; but lamps of later patterns with long arcs and two enclosing globes are almost noiseless.

24. In wiring for low-potential arc lamps on continuous-current circuits, it should be remembered that these lamps require a resistance in series with the arc in order to regulate properly. The drop through this resistance is about 30 volts out of 110. Usually it is adjustable and is placed within the structure of the lamp, so that the lamp can be made to burn well on any circuit of from 105 to 120 volts. Since some 30 volts must be lost in any event, there is no need of running large-size wires from the mains to the lamps to avoid the drop, as the resistance in these wires can be used as a portion of the required resistance and the lamp adjusted accordingly. The drop must be in the individual lamp circuit, not in the mains, where it would have no regulating effect, but would be a disadvantage.

Enclosed-arc lamps are made to burn either singly or two in series on 220-volt circuits. Those designed to burn two in series must be procured in pairs adjusted to burn together, otherwise they work poorly, give uneven light, "seesaw," one lamp taking most of the power for a while, and then the other, or refusing to work at all.

When burned singly on 220 volts, the lamp works satisfactorily, but it is not as efficient as lamps of a lower voltage. A 220-volt enclosed-arc lamp consumes about 130 volts at the arc and 90 in the resistance. It requires 2½ amperes, or more, and gives a little less light in proportion to the power it takes than is given by 110-volt lamps. Single 220-volt lamps are a convenience, however, in places where one lamp only is desired and other current cannot be secured. They are far more economical as light producers than 220-volt incandescent lamps. A 110-volt lamp usually takes from 3 to 6 amperes; 5 amperes is a fair average.

25. Enclosed-arc lamps for alternating currents are quite simple to operate and are efficient. While the arc itself does not give as much light as an 80-volt continuous-current arc of the same watts input, there is not so much power lost in artificial resistance for regulating purposes.

GENERAL RULES.

26. In wiring for electric lights and power, there are certain rules that apply equally to all systems and voltages. These rules will be our first study. In what follows, rules taken from the National Electrical Code are printed as below to distinguish them from the explanations and other matter. In most localities these rules have the force of laws.

GENERAL RULES—ALL SYSTEMS AND VOLTAGES.

Copper for insulated conductors must never vary in diameter so as to be more than $\frac{2}{1000}$ inch less than the specified size.

Wires and cables of all kinds designed to meet the following specifications must be plainly tagged or marked as follows:

1. The maximum voltage at which the wire is designed to be used.

2. The words "National Electrical Code Standard."

3. Name of the manufacturing company and, if desired, trade name of the wire.

4. Month and year when manufactured.

Wires—

a. Must not be of smaller size than No. 14 B. & S., except in fixtures and flexible cords. This is because wires of smaller size are likely to break or become loose, so that the work does not remain mechanically secure, and because a small wire is much more likely to be overloaded by connecting a few additional lamps to it than is a larger wire.

b. Tie-wires must have an insulation equal to that of the conductors they confine.

c. Must be so spliced or joined as to be both mechanically and electrically secure without solder; they must then be soldered to insure preservation, and the joint covered with an insulation equal to that on the conductors.

Stranded wires must be soldered before being fastened under clamps or binding screws, and when they have a conductivity greater than No. 10 B. & S. copper wire, they must be soldered into lugs.

All joints must be soldered, even if made with some form of patent splicing device. This ruling applies to joints and splices in all classes of wiring covered by these rules.

27. Whenever possible to avoid making joints, it is advisable to do so; but where joints are necessary, great care must be taken to do the soldering well, and to leave no acid on the wire. There are several soldering mpounds now on the market that will tin the wire well ough to make a good joint and yet leave no acid on it.

lering Fluid.—

The following formula for soldering fluid is suggested:

Saturated solution of zinc chloride	5 parts.
Alcohol	4 parts.
Glycerine	1 part.

Joints.—Figs. 7, 8, and 9 illustrate joints in com- use. In removing the insulation from the wires where joints or connections are necessary, and in scraping the wire to clean it before making nt, great care be exercised not to cut into and lessen ion and, , its car capacity. Especial care must be taken in handling fixture wires, which are small and easily cut or broken. A comparatively small nick in a copper wire will make it liable to break easily. In recovering the wire with insulating tape, a sufficient amount of tape must be used to afford ample protection. Where rubber-covered wires are spliced or joined, two kinds of tape must be used, the first of pure rubber softened by a volatile oil, and the second of cloth saturated with a moisture-proof adhesive material.

FIG. 7.

FIG. 8.

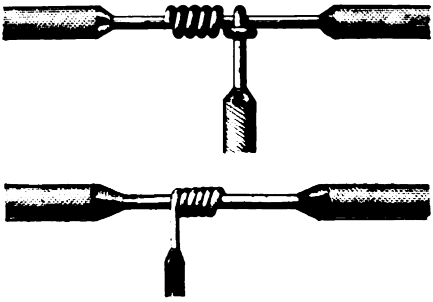


FIG. 9.

29. Rules Relating to Wires (Continued).—

Wires—

d. Must be separated from contact with walls, floors, timbers, or partitions through which they may pass by non-combustible, non-absorptive insulating tubes, such as glass or porcelain.

Bushings must be long enough to bush the entire length of the hole in one continuous piece, or else the hole must first be bushed by a continuous waterproof tube, which may be a conductor, such as iron pipe; the tube is then to have a non-conducting bushing pushed in at each end so as to keep the wire absolutely out of contact with the conducting pipe.

e. Must be kept free from contact with gas, water, or other metallic piping, or any other conductors or conducting material that they may cross, by some continuous and firmly fixed non-conductor, creating a separation of at least 1 inch. Deviations from this rule may sometimes be allowed by special permission.

f. Must be so placed in wet places that an air space will be left between conductors and pipes in crossing, and the former must be run in such a way that they cannot come in contact with the pipe accidentally. Wires should be run over, rather than under, pipes upon which moisture is likely to gather or which, by leaking, might cause trouble on a circuit.

Underground Conductors—

a. Must be protected, when brought into a building, against moisture and mechanical injury, and all combustible material must be kept removed from the immediate vicinity.

b. Must not be so arranged as to shunt the current through a building around any catch box.

This refers to catch boxes in the street, from which the wires should run to the buildings, and not from street to building, building to building, and back again into the street, around one or more catch boxes, thus shunting whatever protective devices there may be in the catch boxes.

TABLE III.

CARRYING CAPACITY OF INSULATED WIRES.

. & S. Gauge.	Rubber-Covered Wires. Amperes.	Weather-proof Wires. Amperes.	Circular Mils.
18	3	5	1,624
16	6	8	2,583
14	12	16	4,107
12	17	23	6,530
10	24	32	10,380
8	33	46	16,510
6	46	65	26,250
5	54	77	33,100
4	65	92	41,740
3	76	110	52,630
2	90	131	66,370
1	107	156	83,690
0	127	185	105,500
00	150	220	133,100
000	177	262	167,800
0000	210	312	211,600
	200	300	200,000
	270	400	300,000
	330	500	400,000
	390	590	500,000
	450	680	600,000
	500	760	700,000
	550	840	800,000
	600	920	900,000
	650	1,000	1,000,000
	690	1,080	1,100,000
	730	1,150	1,200,000
	770	1,220	1,300,000
	810	1,290	1,400,000
	850	1,360	1,500,000
	890	1,430	1,600,000
	930	1,490	1,700,000
	970	1,550	1,800,000
	1,010	1,610	1,900,000
	1,050	1,670	2,000,000

30. Carrying Capacities of Wires.—As any wire carrying an electric current is somewhat heated, it is necessary to know how much current can safely be carried on a wire of a given size. The foregoing table (Table III) supplies this information.

Table of Carrying Capacity of Wires.—

> The accompanying table (Table III), which must be followed in placing interior conductors, shows the allowable carrying capacity of wires and cables of 98 per cent. conductivity, according to the standard adopted by the American Institute of Electrical Engineers.
>
> The lower limit is specified for rubber-covered wires to prevent gradual deterioration of the high insulation by the heat of the wires, but not from fear of igniting the insulation. The question of drop is not taken into consideration in the above table.
>
> The carrying capacity of Nos. 16 and 18 wire is given, but no smaller than No. 14 is to be used, except as allowed for fixture work and flexible cord.

31. Wire Gauges.—It sometimes happens that wires of scant size are sold to the unwary. A workman constantly using wires of various sizes soon learns to gauge the size of wires by his eye, but it is better to use a wire gauge frequently to avoid mistakes. A wire of given size should just enter the slot intended for that size in the style of gauge shown in Fig. 10. Gauges in the form of a vernier caliper, measuring the diameter of the wire in **mils**, are usually more accurate. A mil is **another name for a** thousandth of an inch; for example, a

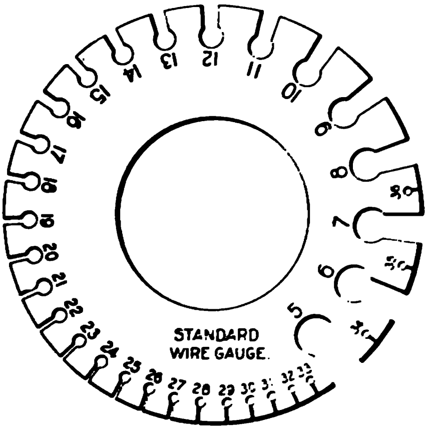


Fig. 10

wire .18 inch in diameter has a diameter of 180 mils. When the diameter in mils is known, the gauge number can be found by referring to the table of dimensions of wires given in Table IV.

We are now ready to discuss the requirements of wiring for particular purposes, beginning with low-potential systems.

TABLE IV.

DIMENSIONS OF BARE COPPER WIRE B. & S. GAUGE.

Gauge Number.	Diameter. Mils.	Area. Circular Mils.	Gauge Number.	Diameter. Mils.	Area. Circular Mils.
0000	460.0	211,600.0	8	128.5	16,509.0
000	409.6	167,805.0	9	114.4	13,094.0
00	364.8	133,079.4	10	101.9	10,381.0
0	324.9	105,534.5	11	90.7	8,234.0
1	289.3	83,694.2	12	80.8	6,529.9
2	257.6	66,373.0	13	72.0	5,178.4
3	[illegible]	[illegible]	14	64.1	4,106.8
4	[illegible]	[illegible]	15	57.1	3,256.7
5	[illegible]	[illegible]	16	50.8	2,582.9
6	[illegible]	[illegible]	17	45.3	2,048.2
7	[illegible]	[illegible]	18	40.3	1,624.3

WIRING FOR LOW-POTENTIAL SYSTEMS.

32. Definition of Low-Potential System.—

LOW-POTENTIAL SYSTEMS.

550 Volts or Less.—

Any circuit attached to any machine or ***combination*** *of machines that develops a* ***difference of potential*** *between any two wires of over 10* ***volts and*** *less than 550 volts shall be considered as a low-potential circuit and as coming under this class unless an approved transforming device is used that cuts the difference of potential down to 10 volts or less. The primary circuit not to exceed a potential of 3,500 volts.*

Before pressure is raised above 300 volts on any previously existing system of wiring, the whole must be strictly brought up to all of the requirements of the rules at date.

Until recently, low-potential systems were limited to 300 volts or under, but the limit has been raised to 550, but 550 volts cannot be applied to old systems unless the above rule is complied with. Low-potential systems are usually constant-potential systems also; that is, the potential or pressure between the terminals of the machine or at some definite points on the line is almost uniform. Only constant-potential systems will be considered under this heading.

A few general rules apply to the various kinds of work under these systems. They are as follows:

33. General Rules.—

Wires—

a. **Must be so arranged that under no circumstances shall there be a difference of potential of over 300 volts between any bare metal in any distributing switch, cut-out cabinet, or equivalent center of distribution.**

b. Must not be laid in plaster, cement, or similar finish and must never be fastened with staples.

c. Must not be fished for any great distance, and only in places where the inspector can satisfy himself that the rules have been complied with.

d. Twin wires must never be used, except in conduits or where flexible conductors are necessary.

e. Must be protected on side walls from mechanical injury. When crossing floor timbers in cellars or in rooms where they might be exposed to injury, wires must be attached by their insulating supports to the under side o[illegible] strip not less than ½ inch in thick[illegible]s than 3 inches in width.

Suitable protection on side walls may be secured by a substantial boxing, retaining an air space of 1 inch around the conductor, closed at the top (the wires passing through bushed holes), and extending not less than 5 feet from the floor; or by an iron-armored or metal-sheathed insulating conduit sufficiently strong to withstand the strain it will be subjected to, and with the ends protected by the lining or by special insulating bushings, so as to thoroughly prevent the possibility of cutting the wire insulation; or by plain metal pipe, lined with tough conduit tubing, which must extend from the insulator next below the pipe to the one next above it.

If metal conduits or iron pipes are used with alternating currents, the two or more wires of a circuit *must* be placed in the same conduit to prevent troublesome induction and heating. They should also be so placed in direct-current wiring if there is any possibility of alternating currents ever being put on the system. In this case, the insulation of each wire must be reenforced by a tough conduit tubing extending from the insulator next below the pipe to the one next above it.

f. When run immediately under roofs or in proximity to water tanks or pipes will be considered as exposed to moisture.

34. The reason for the first part of (*b*) is that plaster and cement are likely to corrode the insulation on the wire and cause it finally to break. If the plaster is damp, leakage takes place, the wire is gradually dissolved by electrolysis, and finally it becomes so thin that it cannot carry its current without excessive heating and, perhaps, not without melting. While there are many places where wires embedded in plaster have been used for years without serious trouble, because of the dryness of the buildings where they are in use, trouble may develop at any time and the practice is always a dangerous one.

The second part of (*b*) is inserted as a direct prohibition against running electric-light wires as bell wires are usually put up. Staples not only do not insulate the wire, but are likely to cut into the insulating covering already on it. Rule (*c*) is to prevent the location of wires where it is impossible to know that they are properly supported and insulated.

SYSTEMS OF DISTRIBUTION FOR INTERIOR WIRING.

35. The voltages in common use on low-potential systems are: for continuous currents, 110 and 220; for alternating currents, 52 and 104. These are used on both two-wire and three-wire systems of wiring. Many lighting companies allow for various amounts of drop at different points on their lines and install lamps of different voltages, as, for instance, 108-volt lamps near the generator and 100-volt lamps at the extreme end of the line, with lamps of intermediate voltages at intermediate points. But the lamps used by any one building are usually all of the same voltage.

36. The Two-Wire System.—This is the simplest plan of wiring and the one in most general use. The sketch, Fig. 11, shows in diagram the essential features of this system. The diagram of connections is the same for all voltages and for alternating or continuous currents; but the fittings, such as lamps, sockets, cut-outs, and switches, and the sizes of wire used will be very different. The fittings and the proper size of wire to be used will be discussed later.

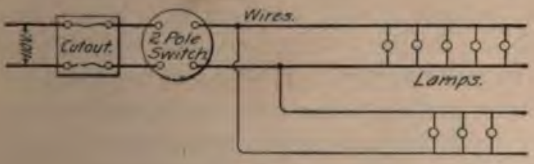


FIG. 11.

37. The Edison Three-Wire System.—This system comes next in importance and extent of use. It also is used with various voltages and with continuous or alternating currents; but its chief field is on continuous-current circuits operated by two generators, with 110 volts between either outer wire and the middle or **neutral** wire and 220 volts between the outer wires. Fig. 12 shows the diagram of connections. This system is also sometimes installed with 220 volts between the neutral and outer wires and 440 volts on the outside wires.

Referring to the diagram, Fig. 12, observe the following: When the currents in the two outside wires are equal in amount, no current passes over the neutral wire; but when

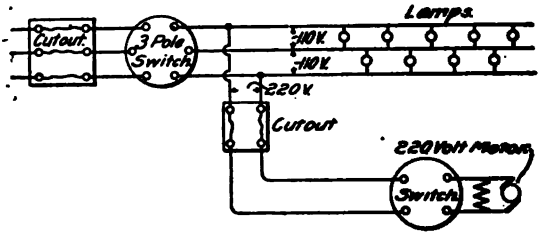


FIG. 12.

the currents are not equal, that is, when more lamps or motors are on one side of the neutral wire than on the other, the "difference current" flows on the middle wire.

38. The advantage of this system is that with lamps of any given voltage it is possible to save in the amount of wire required. In the outside lines of the lighting company is where the greatest saving is effected, because the neutral wire is there much smaller than the outer ones, and three wires are used instead of four, which would have to be run if the generators were operated independently. In interior wiring, the saving is not so great, because the neutral wire must be large enough to carry the current in case all the load is turned off one side of the circuit, as would be the case if the fuse on one side should blow and that on the other side did not, and because in small installations, where unbalancing is likely to occur, three-wire mains must be large to reduce this trouble to a minimum. This subject is explained later.

39. The three-wire system also has some disadvantages. Its most objectionable feature is that if any one line is opened, as by the blowing of a fuse on one line only, the system is unbalanced and a voltage higher than that intended for the apparatus is thrown on the lines, unless the line loss is very small indeed. If it is the middle wire that opens, the whole 220 volts may be thrown on 110-volt apparatus, if the system is much unbalanced. For this reason some Edison companies refuse to place cut-outs on the neutral wire; but the main switch should in all cases open all three lines. Another weakness of the three-wire system is the fact that there is more danger in 220 volts than in 110, and a shock received from a 220-volt circuit may be very severe. The wiring is somewhat more complicated, but owing to the saving in line materials, the Edison three-wire system has been introduced to a very great extent and still meets with much favor in new installations, besides extending the network of its wires from existing stations. Lately it has had a new competitor in the 220-volt two-wire system, which has grown in popularity with the perfecting of the 220-volt incandescent lamp.

40. It is the usual practice to run the three wires no farther within the building than to the centers of distribution, and from these centers to use the two-wire system, dividing the circuits as equally as possible on the two sides of the three-wire circuit, as shown in the sketch, Fig. 13. By this means, the branch lines are fused on both sides and amply protected against excessive currents, though not against high voltage. If the neutral wire within the building is protected by a fuse as large as that in either of the other main wires, the danger of that line opening is very small.

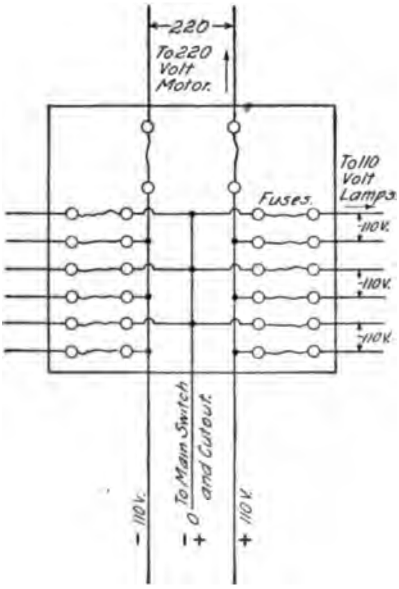


FIG. 13.

41. There is a method of running wires on the two-wire plan that is sometimes confused with the three-wire system; this is illustrated in Fig. 14. In this method the middle wire carries the whole current and each of the two outside wires carry what current is necessary for the lights on its side. This method effects no saving of copper; in fact, it often requires more than the two-wire system would, because the three wires must generally be of the same size, as explained under the subject of cut-out protection. The object of the arrangement is solely to make it possible to turn off a number of the lights without running four wires. The Underwriters will not permit it with more than 660 watts on a side.

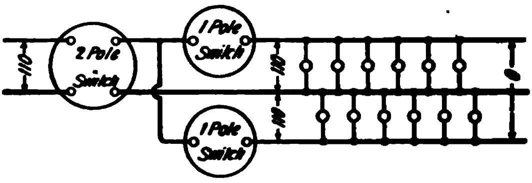


FIG. 14.

42. Systems like the three-wire system, but using more wires and, consequently, more generators, have been proposed; but none of them have come into commercial use to any extent in the United States, because they are easily unbalanced, because some of them give voltages too high for interior wiring (550 volts being the limit of low-tension working), and because they are too complicated. They are used to some extent on the continent of Europe. Fig. 15 is a diagram of such a system. No fittings are shown, but they must be numerous and complicated to make the arrangement approximately practicable.

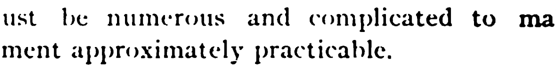


FIG. 15.

MULTIPHASE SYSTEMS.

43. There are several systems for alternating currents only, known as **multiphase systems,** that require three or four wires. These, especially the *three-phase*, the *two-phase*, and the *monocyclic systems*, are very important, and diagrams, with brief descriptions of the essential connections, are therefore given. Fig. 16 represents lamps connected on a **three-phase circuit,** which requires three wires of equal size. The voltage is the same between any two wires, and it is desirable to divide the lights equally across the three pairs of lines, as shown. The sizes of wires for the branch lines (two-wire circuits) may be calculated as for any other two-wire circuit, as is explained later. The mains are of the same size as would be required if there were four wires, two on each of two separate two-wire circuits carrying the same total number of lamps. This system is easily unbalanced if the lamps are not equally divided. Cut-outs and switches (not shown on the sketch) must protect all three wires.

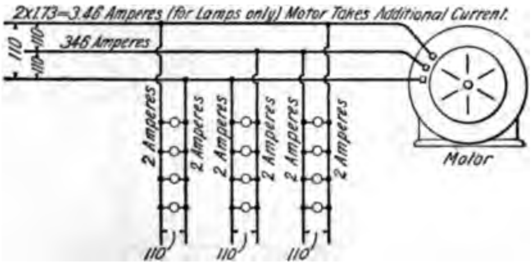


FIG. 16.

44. In a three-phase system, like that shown in Fig. 16, the current in the main wires is found by multiplying the current in the branch circuits by $\sqrt{3} = 1.73$. This assumes that the load on the three phases is balanced, as it should be in practice. This may be written in the form

$$C_m = C_b \times 1.73, \qquad (1.)$$

where C_m = current in each of the main wires;
C_b = current in branches.

In Fig. 16, the current in each branch is 2 amperes; hence, the current in the mains is $2 \times 1.73 = 3.46$ amperes. The method of determining the size of the mains will be taken up in connection with wiring calculations.

45. In the **two-phase system** the wires are sometimes arranged as in the Edison three-wire system, but the middle wire carries more current than either of the outer wires, instead of less. If the current in the outer wires is C and the current in the middle wire C_m, then

$$C_m = C \times 1.41. \qquad (2.)$$

The arrangement of circuits is as in Fig. 17. Lamps are connected between either outer wire and the middle wire and not between the outer wires. The system is easily unbalanced. Three wires are run to the motors. Two-phase systems are generally installed as two separate two-wire systems, four wires being run to the motors and the lights being divided equally on the two two-wire circuits. This gives better regulation (see Fig. 18). In this case, the

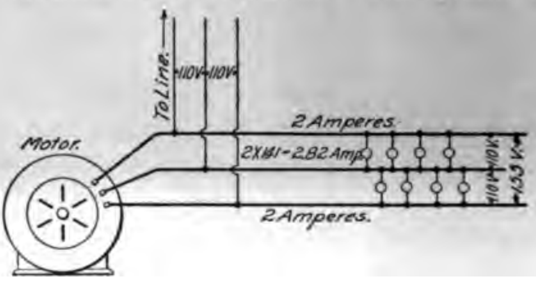


FIG. 17.

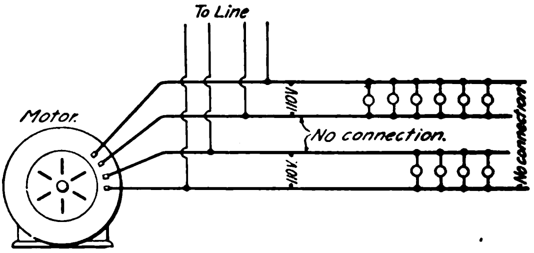


FIG. 18.

current in each of the four wires will be one-half that which would flow if all the lamps were operated on a regular two-wire system.

46. The **monocyclic system** is used only in transmission and in connection with motors. Wiring for lights on a monocyclic circuit is just the same as on any other two-wire circuit of the same voltage. The third wire is brought in only when a motor is installed. For its connections see Fig. 19.

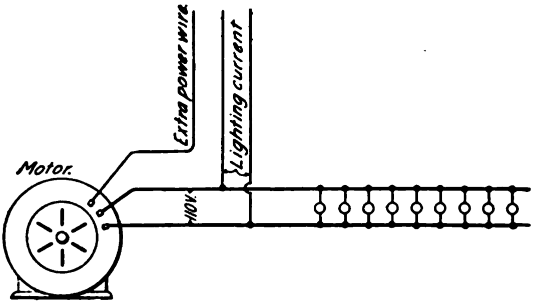


FIG. 19.

47. Generally speaking, multiphase circuits are used in transmission of power only, and not to distribute current to individual lamps. For final distribution, two-wire circuits should be used, and either connected with the three or four multiphase lines at the distribution center or supplied with single-phase current by the use of suitable transformers.

48. House wiring should consist of two distinct portions: the **distribution circuits**, which run from the lamps to a **center of distribution** and which should always be two-wire circuits, and the **mains**, which run from the outside lines to the distribution center and which must conform to the requirements of the particular system to be used. If mains must be installed before it is known what system is to supply current, it will be sufficient to run four separate wires of the size required if the lamps were to be divided equally between two separate two-wire systems. This will make it possible to connect to any system operating at the voltage for which the wiring calculations are made.

SWITCHES AND CUT-OUTS.

49. There are certain devices for the protection of constant-potential systems that are necessary no matter what voltage is used. Should anything happen to damage the wiring, it is necessary that the wires be disconnected from the source of supply of current with the least possible delay. The devices for this purpose that are operated by hand are called **switches**. Those that work automatically are called **automatic cut-outs**. These latter are of two kinds, **fuse blocks** and **circuit-breakers**.

Both a switch and an automatic cut-out must be placed at or near the place where wires enter a building. They must also be placed at various other points on the wiring.

50. The object of the cut-out is to protect the wires and the devices connected to them from damage due to the presence of too much current from any cause whatever. The ordinary cut-out consists of a porcelain base that carries suitable terminals for holding a piece of fusible wire, or **fuse**, which melts and opens the circuit whenever the current becomes excessive. Not only must the cut-out protect the lines when there is trouble, but it must be so placed that it can be reached to replace the fuse or reset the circuit-breaker when the trouble is remedied. It must also be arranged so that the blowing of a fuse or the opening of a circuit-breaker cannot do any damage.

51. Switches are designed to disconnect the lines from the source of electricity, not only when there is trouble, but when convenience requires, as in turning off lights, starting and stopping motors.

Circuit-breakers are not as commonly used in interior wiring work as are fusible cut-outs. They are automatic switches controlled by an electromagnet and are made in a number of different styles. Whenever the current exceeds that for which the circuit-breaker is adjusted, the electromagnet attracts its armature and releases the switch, thus opening the circuit.

The following rules regarding these devices must be ollowed in all cases:

Switches, Cut-Outs, Circuit-Breakers, Etc.—

a. Must, whenever called for, unless otherwise provided, be so arranged that the cut-outs will protect, and the opening of the switch or circuit-breaker will disconnect, all the wires; that is, in a two-wire system the two wires, and in a three-wire system the three wires, must be protected by the cut-out and disconnected by the operation of the switch or circuit-breaker.

b. Must not be placed in the immediate vicinity of easily ignitible stuff or where exposed to inflammable gases or dust or to flyings of combustible material.

NOTE.—In buildings used for starch and candy factories, woodworkers, grain elevators, flouring mills, or other purposes where fittings are exposed to dust and flyings of inflammable material, cut-outs and switches should be placed in an approved cabinet outside of the dust rooms, or if necessary to locate same in the dust room, cabinet must be dust-proof and arranged with a self-closing door.

c. Must, when exposed to dampness, either be enclosed in a waterproof box or mounted on porcelain knobs.

Automatic Cut-Outs (Fuses and Circuit-Breakers)

a. Must be placed on all service wires, either overhead or underground, as near as possible to the point where they enter the building and inside the walls, and arranged to cut off the entire current from the building.

Where the required switch is inside the building, the cut-out required by this section must be placed so as to protect it.

b. Must be placed at every point where a change is made in the size of wire [unless the cut-out in the larger wire will protect the smaller].

This (*b*) means unless the current carried by the larger wire s less than the smaller wire will safely carry, the fuse being roportioned to protect the smaller wire. This is frequently he case when line wires are connected to fixture wires, which are small so that they will go between the shells of fixtures and the gas pipe within.

> *c.* Must be in plain sight or enclosed in an *approved* box and readily accessible. They must not be placed in the canopies or shells of fixtures.

This rule (*c*) precludes the use of the small cut-outs that it was customary at one time to place within the fixture canopies.

> *d.* Must be so placed that no set of incandescent lamps, whether grouped on one fixture or several fixtures or pendants, requiring more than 660 watts shall be dependent on one cut-out. Special permission may be given in writing by the Inspection Department having jurisdiction for departure from this rule in the case of large chandeliers, stage borders, and illuminated signs.

On 52- or 110-volt circuits this is equivalent to not more than twelve 16-candlepower lamps; on 220-volt circuits, not more than ten 16-candlepower lamps. It is best to stay well under this limit, say about six lamps to a cut-out, except in the special cases mentioned in the rule.

> *e.* Must be provided with fuses, the rated capacity of which does not exceed the allowable carrying capacity of the wire, and when circuit-breakers are used, they must not be set more than about 30 per cent. above the allowable carrying capacity of the wire, unless a fusible cut-out is also installed in the circuit.

This is very important. A fuse block not properly fused is of no use whatever. Irresponsible parties sometimes place fuses much too large to protect the wire and which will destroy the cut-out if they should ever blow, besides doing other damage. Sometimes, also, fuse blocks are found having copper wire where the fuses should be; of course, they are of no use with such connections.

52. Circuit-breakers may be set so as to work with greater accuracy than fuses; they respond quicker to sudden overloads, for fuses require a little time to get hot enough to melt. For this reason, circuit-breakers may be set for higher currents than fuses. If they are not so set, they will give trouble by opening the circuit on momentary overloads that would not be sufficient to melt the fuses. Circuit-breakers are usually installed to protect machines, while fuses protect wires and cables of the smaller sizes. Very large fuses should be avoided and circuit-breakers used in their stead. The largest currents should be cut off indirectly, as by lowering the voltage and shutting down the generator. But such very large currents are only used in special low-voltage work, in electrochemical processes, and electric furnaces.

53. Rules Relating to Switches.—

Switches—

> *a.* Must be placed on all service wires, either overhead or underground, in a readily accessible place, as near as possible to the point where the wires enter the building, and arranged to cut off the entire current.
>
> *b.* Must always be placed in dry, accessible places and be grouped as far as possible. Knife switches must be so placed that gravity will tend to open rather than close the switch.
>
> *c.* Must not be single-pole when the circuits that they control supply devices that require over 660 watts of energy or when the difference of potential is over 300 volts.

This rule (*c*) is important, because it restricts the number of lamps so severely.

> *d.* Where flush switches are used, whether with conduit systems or not, the switches must be enclosed in boxes constructed of or lined with fire-resisting material. No push buttons for bells, gas-lighting circuits, or the like shall be placed in the same wall plate with switches controlling electric-light or power wiring.

This requires an approved box in addition to the porcelain enclosure of the switch.

e. Where possible, at all switch or fixture outlets, a ⅞-inch block must be fastened between studs or floor timbers, flush with the back of lathing, to hold tubes and to support switches or fixtures. When this cannot be done, wooden base blocks not less than ¾ inch in thickness, securely screwed to the lathing, must be provided for switches and also for fixtures that are not attached to gas pipes or conduit tubing.

54. Construction of Cut-Outs, Circuit-Breakers, Etc. Equally important as the location of these devices is their proper construction. The following rules should be given careful study before any of these supplies are purchased.

Cut-Outs and Circuit-Breakers—

a. Must be supported on bases of non-combustible, non-absorptive, insulating material.

b. Cut-outs must be provided with covers, when not arranged in approved cabinets, so as to obviate any danger of the melted fuse metal coming in contact with any substance that might be ignited thereby.

c. Cut-outs must operate successfully, under the most severe conditions they are liable to meet with in practice, on short circuits with fuses rated at 50 per cent. above and with a voltage 25 per cent. above the current and voltage for which they are designed.

d. Circuit-breakers must operate successfully, under the most severe conditions they are liable to meet with in practice, on short circuits when set at 50 per cent. above the current and with a voltage 25 per cent. above that for which they are designed.

e. Must be plainly marked, where it will always be visible, with the name of the maker and the current and voltage for which the device is designed.

Fuses—

a. Must have contact surfaces or tips of harder metal having perfect electrical connection with the fusible part of the strip.

b. Must be stamped with about 80 per cent. of the maximum current they can carry indefinitely, thus allowing about 25 per cent. overload before fuse melts.

With naked, open fuses of ordinary shapes and not over 500 amperes capacity, the *maximum* current that will melt them in about 5 minutes may be safely taken as the melting point, as the fuse practically reaches its maximum temperature in this time. With larger fuses a longer time is necessary.

Enclosed fuses, where the fuse is often in contact with substances having good conductivity to heat and often of considerable volume, require a much longer time to reach a maximum temperature, on account of the surrounding material, which heats up slowly.

c. Fuse terminals must be stamped with the maker's name, initials, or some known trade mark.

55. The Underwriters' Rules relating to switches specify in detail the requirements that a switch must fulfil. Most of these requirements relate to mechanical details that concern the switch manufacturer more than the wireman. The style of switches used for interior wiring will be described later, and we will at this point simply call attention to a few rules relating to ordinary snap or push switches that are more directly connected with the installation of interior wiring.

Snap Switches.—

a. The current-carrying parts must be mounted on non-combustible, non-absorptive, insulating bases, such as slate or porcelain, and the holes for supporting screws shall be countersunk not less than $\frac{1}{8}$ inch; in no case must there be less than $\frac{3}{64}$ inch space between supporting screws and current-carrying parts.

Subbases that will separate the wires at least $\frac{1}{2}$ inch from the surface wired over should be furnished for all snap switches used in exposed knob or cleat work.

b. Covers made of conducting material, except face plates for flush switches, must be lined on their sides and top with insulating, tough, and tenacious material at least $\frac{1}{32}$ inch in thickness, firmly secured, so that it will not fall out with ordinary handling. Side lining should extend slightly beyond the lower edge of the cover.

c. The handle, button, or any exposed part must not be in electrical connection with the circuit.

d. Must "make" and "break" with a quick snap and not stop when motion has once been imparted to the handle.

Must operate successfully at 50 per cent. overload in amperes and 25 per cent. excess voltage under the most severe conditions they are liable to meet in practice.

When slowly turned "on" and "off" at the rate of about two or three times per minute, must "make" and "break" the circuit 6,000 times before failing, while carrying the rated current.

e. Must be plainly marked, where it may be readily seen after the device is installed, with the name or trade mark of the maker and the current or voltage for which the switch is designed.

On flush switches, these markings may be placed on the back of the face plate or on the subplate. On other designs, they must be placed on the *front* of the cap, cover, or plate.

Switches that indicate upon inspection whether the current be "on" or "off" are recommended.

Some of the common styles of switches and cut-outs will be described later when the methods of wiring are taken up.

OPEN WORK IN DRY PLACES.

56. Open work is generally used in factories, warehouses, mills, and other places where there is no objection to having the wires in plain sight, or in old buildings, where the expense of concealed work overbalances the objectionable appearance in the mind of the owner of the house or of the tenant. It is the cheapest kind of construction and very often the safest. We will study how to wire a building by means of simple examples.

SIMPLE EXAMPLE OF FACTORY WIRING.

57. Consider a factory, such as a long machine shop, where there is but one floor to be wired. It is proposed to wire this for 110-volt enclosed-arc lamps and incandescent lamps on the so-called **tree system**; that is, with but one set of mains or feeder wires leaving the dynamo and with other lines branching from these mains to the points where lamps are required. Let Fig. 20 represent the outlines of such a factory, in which incandescent lamps are to be hung on lamp cord at the points marked × and enclosed-arc lamps are to be placed where the marks O are shown. Let us first consider what is the cheapest way in which this factory can be wired in order to satisfy the Underwriters; then we will see what modifications can be made to better the light, improve the system, and make it more convenient and economical in operation.

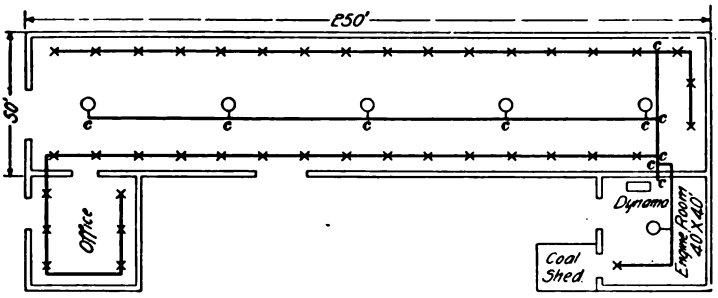


FIG. 20.

58. We will assume that each incandescent lamp is to be allowed 55 watts. Some good lamps take less power, but it is not safe to count on less. We also assume that each enclosed arc is to take 5 amperes while burning and 12 amperes to start on. There are 40 incandescent lamps and 6 arc lamps to be wired.

55 (watts) ÷ 110 (volts) = .5 (ampere per lamp),
40 × .5 = 20 (amperes for incandescent lamps),
6 × 5 = 30 (amperes for arc lamps),
Total amperes = 50,

which must be carried on the mains for a short distance at least.

Referring now to the table of Safe Carrying Capacities

(Table III), we see that the smallest wire that will carry 50 amperes with safety is No. 6 weather-proof.

59. Rules Relating to Wires for Open Work.—For open work in dry places we have the following rules regarding wires:

Wires—

a. Must have an *approved* rubber or "slow-burning" weather-proof insulation.

b. Must be rigidly supported on non-combustible, non-absorptive, insulators that will separate the wires from each other and from the surface wired over in accordance with the following table:

Voltage.	Distance From Surface. Inch.	Distance Between Wires. Inches.
0 to 300	½	2½
300 to 500	1	4

Rigid supporting requires under ordinary conditions, where wiring along flat surfaces, supports at least every 4½ feet. If the wires are liable to be disturbed, the distance between supports should be shortened. In buildings of mill construction, mains of No. 8 B. & S. wire or over, where not liable to be disturbed, may be separated about 4 inches and run from timber to timber, not breaking around, and may be supported at each timber only.

This rule will not be interpreted to forbid the placing of the neutral of a three-wire system in the center of a three-wire cleat, provided the outside wires are separated 2½ inches.

Slow-burning weather-proof wire is cheaper than rubber-covered wire and is suitable for this purpose. Various manufacturers make it. The following specifications will enable the wireman to determine whether wire offered him is up to the standard.

Slow-Burning Weather-Proof.—

a. The insulation shall consist of two coatings, one to be fireproof in character, the other to be weather-proof. The inner fireproof coating must comprise at least $\frac{6}{10}$ of the total thickness of the wall. The completed covering must be of a thickness not less than that given in the following table for B. & S. gauge sizes:

Sizes of Wires Between Numbers.	Thickness of Insulation. Inch.
14–8	$\frac{3}{64}$
7–2	$\frac{1}{16}$
2–0000	$\frac{5}{64}$
0000–500,000	$\frac{3}{32}$
500,000–1,000,000	$\frac{7}{64}$
over 1,000,000	$\frac{1}{8}$

Measurements of insulating wall are to be made at the thinnest portion. Either the fireproof or the weather-proof coating may be on the outside.

b. The fireproof coating shall be layers of cotton or other thread, the outer one of which must be braided. All the interstices of these layers are to be filled with the fireproofing compound. This is to be material whose solid constituent is not susceptible to moisture, and which will not burn even when ground in an oxidizable oil, making a compound that, while proof against fire and moisture, at the same time has considerable elasticity and that when dry will suffer no change at a temperature of 250° F. and that will not burn at even higher temperature.

c. The weather-proof coating shall be a stout braid thoroughly saturated with a dense moisture-proof compound thoroughly slicked down, applied in such manner as to drive any atmospheric moisture from the cotton braiding, thereby securing a covering to a great degree waterproof and of high insulating power. This compound to retain its elasticity at 0° F. and not to drip at 160° F.

This wire is not as liable to burn as the old "weather-proof" nor as subject to softening under heat, but still is able to repel the ordinary amount of moisture found indoors. It would not usually be used for outside work.

60. Determination of Sizes of Wire According to Current Capacity.—Observing the location of the lamps as shown in the diagram, we see that on each side of the building and down the center they are arranged in straight lines. It is evident, therefore, that it will be easier to run the wires along these lines and to fasten the rosettes (small porcelain fittings from which the lamps are suspended) directly to them, rather than put in short branch lines and run the principal wires on any other lines. We will, therefore, run the wires as shown in the sketch, where each line is supposed to represent a pair of wires put up on knobs or cleats.

61. We have now 18 incandescent lamps on one line, 21 on another, 5 arc lamps on a third, and 1 arc lamp and 1 incandescent lamp on a fourth. Referring again to the table of Carrying Capacities, we find that these lines will require wires of the following sizes: 21 incandescent lamps (10.5 amperes), No. 14 wire; 18 incandescent lamps (9 amperes), No. 14 wire; 5 arc lamps (25 amperes), No. 10 wire; 1 arc lamp and 1 incandescent lamp (5.5 amperes), No. 14 wire.

62. Location of Cut-Outs. — Since not more than 660 watts can be dependent on one cut-out, if we lay out the wiring as stated thus far, it will be necessary to have fuses in all the rosettes and also a separate cut-out at each arc lamp. Besides these cut-outs, there must be a cut-out at the point where each branch line joins the mains. The small wires running from the cut-outs to the arc lamps may be No. 14, which is large enough to carry the starting current of 12 amperes continually, if necessary. The locations of the cut-outs are indicated on the diagram by the letter *c*.

63. The wiring as now laid out, if put up properly, will comply with all the Underwriters' rules. The main switch and cut-out should be located near the dynamo in the engine room.

Such an arrangement as just described would not necessarily give satisfaction; it would merely be safe. But before entering upon the matter of how to improve the plan of the wiring, we will consider some of the fittings and methods of work that should be used upon an installation of this kind.

FITTINGS USED FOR EXPOSED WIRING.

64. Open work must always be put up as though there were no insulation whatever on the wires themselves. The wires must be supported on insulators so as not to come into contact with any woodwork, pipes, or any other thing except insulating supports.

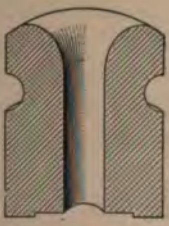


FIG. 21.

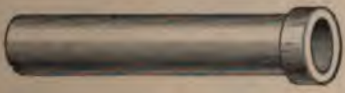


FIG. 22.

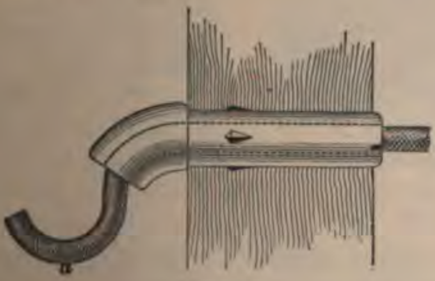


FIG. 23.

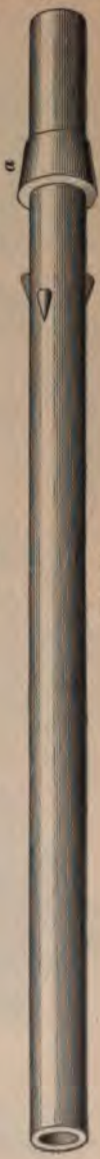


FIG. 24.

65. Fittings for Supporting Wire.—Some varieties of porcelain fittings suitable for this kind of work are shown in Figs. 21 to 30. These figures are typical examples only. Fittings of quite different designs may be used if they comply with the rules.

Fig. 21 shows an ordinary porcelain **knob** in section. These are made in various sizes, and the size used will depend somewhat on the size of wire to be accommodated. Fig. 22 shows the common 4-inch porcelain **tube** used where wires are run through joists. Fig. 23 is the style of tube used where wires are brought through window frames from the outside. The end is curved downwards to prevent water running in, and the **drip loop** *a* is formed to allow the water to drip off. A similar tube, only longer, is used for bringing wires in through brick or stone walls. Fig. 24 is a long, straight, porcelain tube used for passing through walls or floors. Note that the head *a* is some distance from the end, so that when the tube is used for carrying wires through floors, the exposed part of the wire will be above the floor.

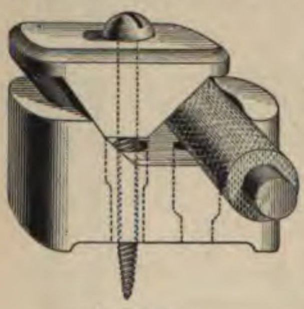


FIG. 25.

Fig. 25 is a single-wire **cleat,** used more particularly for supporting fairly large wires. Fig. 26 shows a two-wire cleat designed to support the wires 2½ inches apart, in order to conform with the Underwriters' requirements. Many

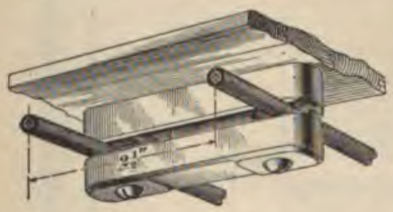


FIG. 26.

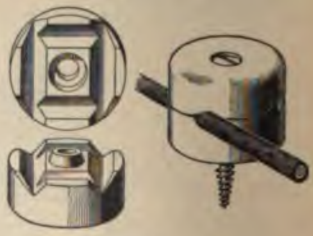


FIG. 27.

different styles of cleats are made, but they are much the same in general construction. It is always best to put up cleats and knobs with screws, as a better job is done than when nails are used. Nails are, however, sometimes used, a leather washer being placed between the nail head and the porcelain, to prevent the latter from being cracked. Fig. 27 is a **knob cleat** used for supporting single wires where something neater than the ordinary knob is desired. It does away with the necessity of a tie-wire and is provided with four different sized grooves so that it will accommodate wires of various thicknesses. Fig. 28 shows a double-headed tube used when wires cross each other. Porcelain tubes should always be used where crossings of this kind occur. The tube, Fig. 22, is frequently used for this purpose; but if this is done, the end without a head should be taped to the wire to prevent the tube sliding along. Fig. 29 shows a fused **rosette** or ceiling cut-out. These rosettes are made in two parts, *a* and *b*. Part *a* is screwed to the

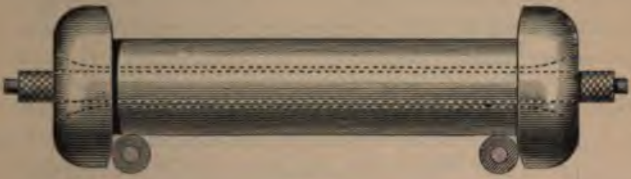


FIG. 28.

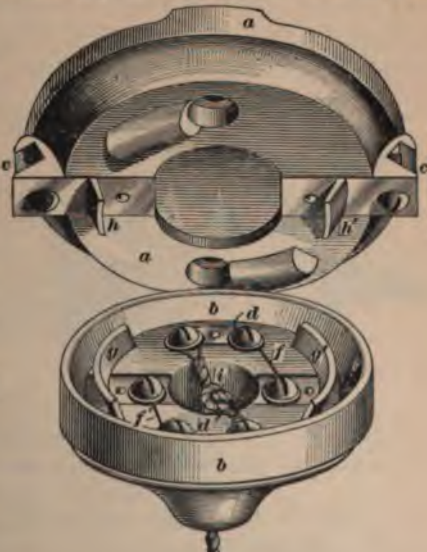


FIG. 29.

ceiling and the lamp is hung from the cap b. The lines are attached to the terminals c, c' and the lamp cord to d, d'; f, f' are the small fuses. When the cover b is attached to a by a twisting movement, terminals g, g' lock with h, h' and make the connection from the mains to the lamp. The cord should be knotted at i so that the pull will not come on the connections d, d'.

66. For such work as is now being considered, the principal porcelain articles required are the cleat, the rosette, and the cut-out. These are all made in several forms; some cleats are to be fastened with nails, others with screws. The selection of such fittings must be made with reference to the work in hand; for instance, cleats cannot be put up with nails on plastered walls, because the driving of nails will crack the plaster.

If the wires are placed high out of reach and the distance between the points of support is considerable, they should be separated a foot or more and fastened to knobs. Where passing through walls or partitions, the wires should be protected by porcelain bushings.

If a lamp is needed not more than 3 feet from the direct line of the wires, it can be hung where required by means of a **ceiling button,** Fig. 30; but lamp cord must not be used to run lamps in this way more than 2 or 3 feet from the rosette.

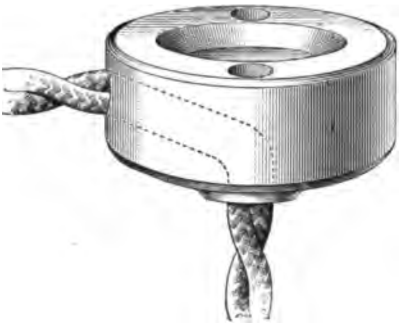


FIG. 30.

67. Flexible Lamp Cord.—In selecting lamp cord for this kind of work and in securing good sockets, too much care cannot be taken, for trouble occurs more frequently in lamp cord and sockets than in any other part of the wiring, if these articles are not of the highest grade. There is much temptation to use lamp cord for other purposes than those for which it is designed. The rules regarding it are given here, and special attention is directed to them :

Flexible Cord—

a. Must have an *approved* insulation and covering.

b. Must not be used where the difference of potential between the two wires is over 300 volts.

c. Must not be used as a support for clusters.

d. Must not be used except for pendants, wiring of fixtures, and portable lamps or motors.

e. Must not be used in show windows.

f. Must be protected by insulating bushings where the cord enters the socket.

g. Must be so suspended that the entire weight of the socket and lamp will be borne by knots under the bushing in the socket, and above the point where the cord comes through the ceiling block or rosette, in order that the strain may be taken from the joints and binding screws.

68. As there is much inferior lamp cord on the market, the specifications for lamp cord are given here. Only brands that comply with these specifications should be used.

Flexible Cord—

a. Must be made of stranded copper conductors, each strand to be not larger than No. 26 or smaller than No. 30 B. & S. gauge, and each stranded conductor must be covered by an approved insulation and protected from mechanical injury by a tough, braided outer covering.

For pendant lamps:

In this class is to be included all flexible cord that, under usual conditions, hangs freely in air and that is not likely to be moved sufficiently to come in contact with surrounding objects.

b. Each stranded conductor must have a carrying capacity equivalent to not less than a No. 18 B. & S. gauge wire.

c. The covering of each stranded conductor must be made up as follows:

1. A tight, close wind of fine cotton.

2. The insulation proper, which shall be either waterproof or slow-burning.

3. An outer cover of silk or cotton.

The wind of cotton tends to prevent a broken strand puncturing the insulation and causing a short circuit. It also keeps the rubber from corroding the copper.

d. Waterproof insulation must be solid, at least $\frac{1}{32}$ inch thick, and must show an insulation resistance of 50 megohms (50 million ohms) per mile throughout two weeks' immersion in water at 70° F., and stand the tests prescribed for low-tension wires as far as they apply.

e. Slow-burning insulation must be at least $\frac{1}{32}$ inch in thickness and composed of substantial, elastic, slow-burning materials that will suffer no damage at a temperature of 250° F.

f. The outer protecting braiding should be so put on and sealed in place that when cut it will not fray out, and where cotton is used, it should be impregnated with a flame-proof paint that will not have an injurious effect on the insulation.

For portables:

In this class is included all cord used on portable lamps, small portable motors, etc.

g. Flexible cord for portable use must have waterproof insulation, as required in section *d* for pendant cord, and, in addition, must be provided with a reenforcing cover especially designed to withstand the abrasion it will be subject to in the uses to which it is to be put.

For portable heating apparatus:

h. Must be made up as follows:

1. A tight, close wind of fine cotton.

2. A thin layer of rubber about $\frac{1}{100}$ inch thick or other cementing material.

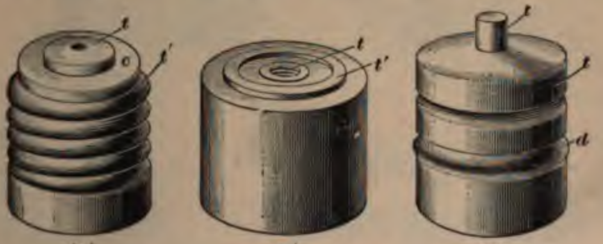
3. A layer of asbestos insulation at least $\frac{3}{64}$ inch thick.

4. A stout braid of cotton.

5. An outer reenforcing cover especially designed to withstand abrasion.

This cord is in no sense waterproof, the thin layer of rubber being specified in order that it may serve merely as a seal to help hold in place the fine cotton and asbestos, and it should be so put on as to accomplish this.

69. Lamp Bases.—The style of lamp socket used in a given job of wiring will depend on the kind of **bases** that are on the lamps. A large number of different styles of lamp bases have been brought out, but the number has gradually been cut down until the three types shown in Fig. 31 cover practically all the lamps in use in the United States; these are the Edison (*a*), the Thomson-Houston (*b*), and the Sawyer-Man, or Westinghouse (*c*). Of these three, the Edison base is the most popular and is gradually superseding the other two. In each case, the terminals of the socket are marked *t*, *t'*. When the lamp is placed in the socket, these make connection with corresponding terminals, thus connecting the circuit with the lamp.



(*a*) (*b*) (*c*)

FIG. 31.

70. Lamp Sockets and Receptacles.—A large variety of lamp sockets are manufactured, but they are all much the same in general design. Some of these are provided with keys for turning the light off or on; others are keyless—the light being controlled by a separate switch. The main thing to look out for in selecting sockets is to see that they are substantial, one of the most common sources of trouble on incandescent-lighting circuits being flimsy sockets that are continually getting out of order. Fig. 32 shows a typical key socket for an Edison base lamp. Sockets should be so constructed that the shell *a* will be insulated from the wires. Ordinary key sockets are suitable for work with incandescent lamps not exceeding 32 candlepower. The rubber or composition bushing shown in Fig. 33 must be used on all sockets suspended from lamp cord in order to protect the cord where it passes through the shell.

Fig. 34 shows a waterproof, keyless socket for an Edison base. The terminals are surrounded by molded mica insulating material *a* and the wires *b*, *b* are attached directly to the mains. Waterproof sockets are also made of porcelain. Sockets of this type are required by the Underwriters whenever wiring is done in damp places, such as breweries, dye-houses, etc.

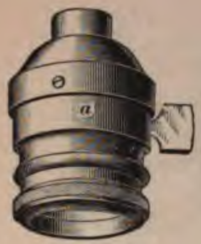


FIG. 32.

FIG. 33.

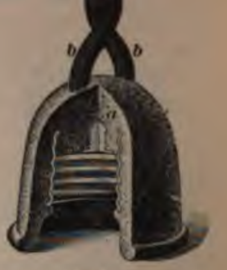
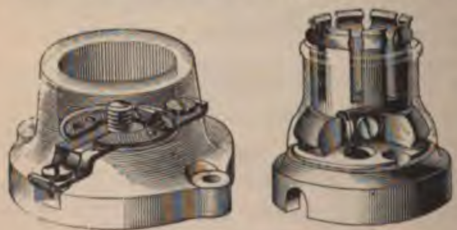


FIG. 34.

Fig. 35 (*a*) and (*b*) shows two styles of keyless receptacles. That shown in Fig. 35 (*a*) is almost entirely of porcelain and is designed for a lamp having a Thomson-Houston (T. H.) base. That shown in Fig. 35 (*b*) is provided with a porcelain base and a brass shell, the terminals being designed to take a Sawyer-Man, or Westinghouse, base.

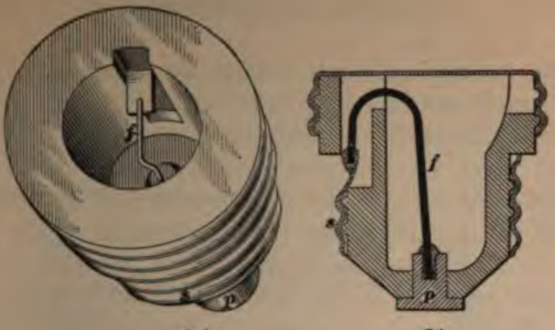


(*a*) (*b*)

FIG. 35.

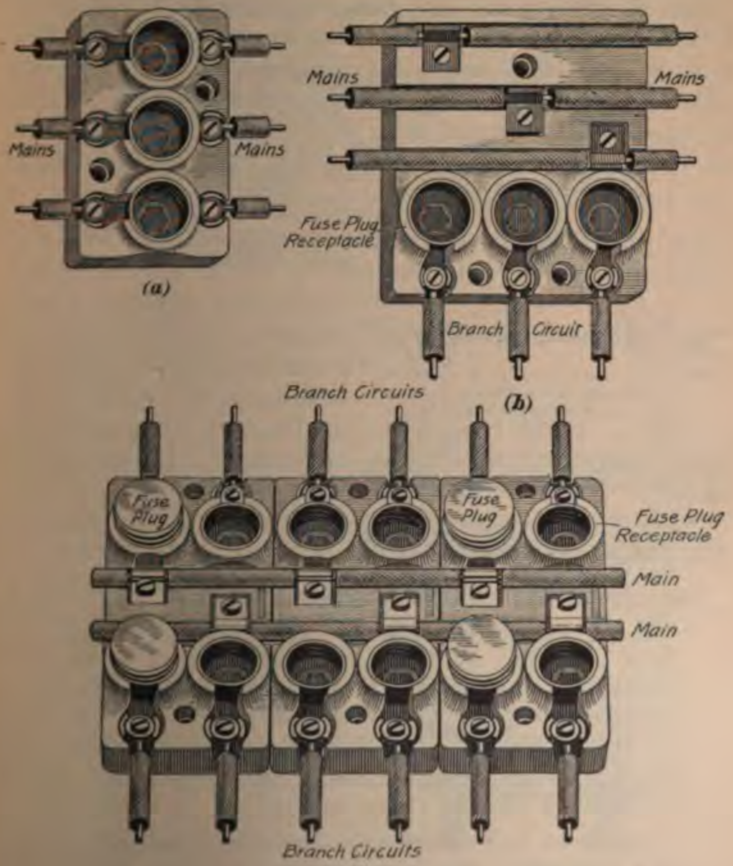
PORCELAIN FUSE BLOCKS.

71. Edison Plug Cut-Outs.—Among the suitable cut-outs for small currents on 52- or 110-volt work are the standard Edison **fuse-plug cut-outs.** These cut-outs are



(a) (b)

FIG. 36.



(a) (b) (c)

FIG. 37.

made for currents of from 5 to 30 amperes. The plug is provided with contacts like those of the Edison lamp base. Cut-outs of this style are made for all combinations of two-wire and three-wire circuits, and several cut-outs can be connected together at a distribution center if desirable.

Fig. 36 (*a*) and (*b*) shows the construction of the Edison fuse plug. The fuse *f* is mounted in a porcelain or glass holder and attached to the screw terminal *s* and the contact *p*. These plugs screw into the receptacles on the fuse block, and whenever a fuse blows, a new plug is inserted.

Fig. 37 (*a*) shows a three-wire **main block** and Fig. 37 (*b*) a three-wire **branch block.** Fig. 37 (*c*) shows three two-wire **double branch blocks** grouped together to form a distributing center. The advantages of this type of fuse are that it is enclosed and that it gives good contact between the fuse and the fuse-block terminals. On the other hand, it is somewhat more expensive than the link fuse.

72. Link Fuses and Fuse Blocks.—Fig. 38 shows an ordinary link fuse. It consists of a fusible wire or strip *c* (generally made of a mixture of lead and bismuth) provided with copper terminals *a*, *b*. These terminals are necessary, because the fuse wire is soft and is almost sure to be cut if placed under the binding screws on the cut-out.

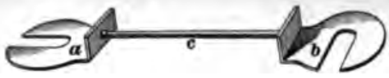


FIG. 38.

When link fuses are used, they must comply with the following specifications:

For Circuits of Not Over 125 Volts.—

Links on non-combustible bases enclosed in fireproof cabinets. Minimum break distance, 1¼ inches; minimum separation of terminals of opposite polarity, unless separated by ample partitions, 1¼ inches. *Fuses to be held free of contact with any portion of the base.*

For Circuits of Not Over 250 Volts.—

Links on non-combustible bases enclosed in fireproof cabinets. Minimum break distance, 2½ inches;

minimum separations of terminals of opposite polarity, unless separated by ample partitions, 2½ inches. *Fuses to be held free of contact with any portion of the base.*

For open work, where the fuse blocks are not enclosed in fireproof cabinets, they must be provided with suitable covers to prevent the melted metal of the fuse wire coming into contact with inflammable material. They should also be so located that no damage will result if the cover is left off.

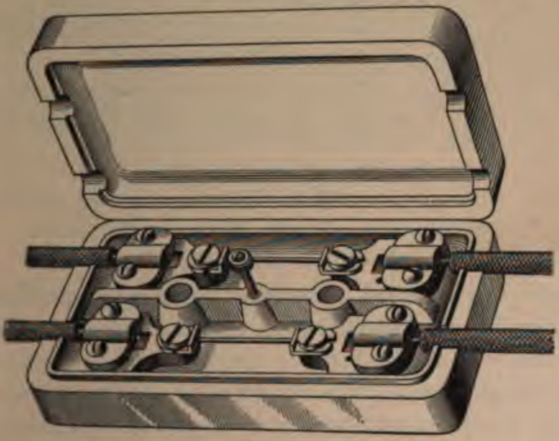


FIG. 39.

Figs. 39 and 40 show two styles of link fuse blocks, Fig. 39 being a main-line block with its cover and Fig. 40 a two-wire branch block with its cover omitted. Some manufacturers rate their wares as capable of carrying larger currents than should be allowed. Care

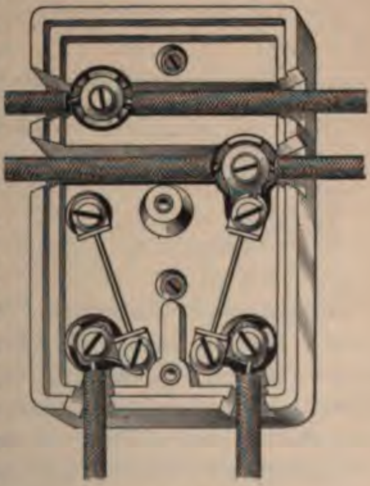


FIG. 40.

should be taken not to use such fittings except within their proper range.

73. Enclosed Fuses.—The use of link fuses is gradually giving way to that of enclosed fuses. The Edison plug is one type of enclosed fuse, but there are many other varieties in which the fuse is sealed in a tube or cartridge filled with material which does not conduct heat readily. The fuse is thus protected from injury and is more likely to melt at its rated capacity. One type of enclosed fuse block is shown in Fig. 44.

WIRING FOR A UNIFORM DROP.

74. In the method of wiring illustrated in Fig. 20, it will be noticed that the lamp on the extreme end of the line in the office is much farther away from the dynamo than the first lamp on that line. Owing to the resistance of the wire, the distant lamp will not burn as brilliantly as the nearer one; therefore, it is desirable to have a system of wiring on which the lamps will all glow with equal brightness. Also, it is not desirable in many cases to have a rosette with a fuse at each lamp, as this means many small fuses. Many very small fuses are not as reliable as a few larger ones and they cause more trouble. We will, therefore, plan to wire this establishment so as to avoid these two undesirable conditions. Fig. 41 represents the factory so

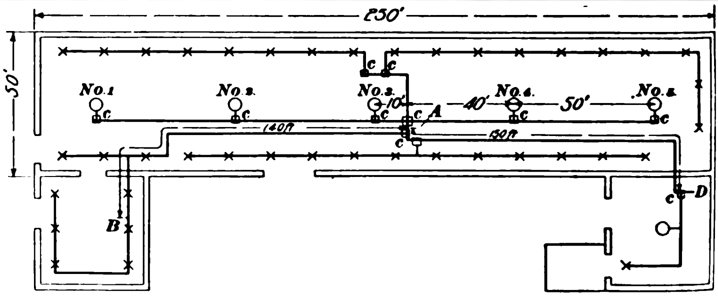


FIG. 41.

wired. Where joints are made without changing the size of the wire, no cut-outs are required. In these wiring diagrams but one line is drawn to represent the two wires that must be installed.

In the wiring diagram shown in Fig. 41, there being less than 660 watts on any branch circuit, fuses may be omitted from the rosettes (or fuseless rosettes installed). Fuses of a proper size to protect the lamp cord must be placed in the cut-outs, that is, 6-ampere fuses if No. 16 cord is used. In such an installation, No. 18 lamp cord cannot be used without fused rosettes, unless not more than 6 lamps are placed on a branch circuit, because a 3-ampere fuse is required to protect No. 18 wire, and if placed in a cut-out, it will not allow current to pass for more than 6 110-volt lamps. The sizes of wires permitted by the insurance rules will be the same as in the first case studied.

75. We will now take up the subject of line calculations with reference to loss of power, or **drop** in potential. Table V gives the resistance of pure copper wire at 75° F. (24° C.), which is the temperature at which wiring calculations are usually made. The conductivity of commercial copper wire is from 98 to 99.5 per cent. of that of pure copper.

In ordinary interior wiring, the variations in resistance due to changes in temperature are usually disregarded, although they must be taken into account in the design of most kinds of electrical apparatus where they affect the regulation very much, as, for instance, in the field coils on a generator. The greatest variation in temperature at all likely to occur, and that will occur but rarely and only in open work, is about 100° F. This will correspond to a change in resistance of about 21 per cent.

The resistances of wires smaller than No. 18 are of no use in practical wiring, but are given for reference, as small wires are used in many pieces of mechanism, such as fan motors, resistance boxes, etc. with which wiremen have to deal, and also in bell and annunciator work.

TABLE V.

RESISTANCE OF PURE COPPER WIRE.

Number B. & S.	Resistance at 75° F.		
	Ohms Per 1,000 Feet.	Ohms Per Mile.	Feet Per Ohm.
0000	.04893	.25835	20,440.000
000	.06170	.32577	16,210.000
00	.07780	.41079	12,850.000
0	.09811	.51802	10,190.000
1	.12370	.65314	8,083.000
2	.15600	.82368	6,410.000
3	.19670	1.03860	5,084.000
4	.24800	1.30940	4,031.000
5	.31280	1.65160	3,197.000
6	.39440	2.08250	2,535.000
7	.49730	2.62580	2,011.000
8	.62710	3.31110	1,595.000
9	.79080	4.17530	1,265.000
10	.99720	5.26570	1,003.000
11	1.25700	6.63690	795.300
12	1.58600	8.37410	630.700
13	1.99900	10.55500	500.100
14	2.52100	13.31100	396.600
15	3.17900	16.78500	314.500
16	4.00900	21.16800	249.400
17	5.05500	26.69100	197.800
18	6.37400	33.65500	156.900
19	8.03800	42.44100	124.400
20	10.14000	53.53900	98.660
21	12.78000	67.47900	78.240
22	16.12000	85.11400	62.050
23	20.32000	107.29000	49.210
24	25.63000	135.53000	39.020
25	32.31000	170.59000	30.950
26	40.75000	215.16000	24.540
27	51.38000	271.29000	19.460
28	64.79000	242.09000	15.430
29	81.70000	431.37000	12.240
30	103.00000	543.84000	9.707
31	129.90000	685.87000	7.698
32	163.80000	864.87000	6.105
33	206.60000	1,090.80000	4.841
34	260.50000	1,375.50000	3.839
35	328.40000	1,734.00000	3.045
36	414.20000	2,187.00000	2.414
37	522.20000	2,757.30000	1.915
38	658.50000	3,476.80000	1.519
39	830.40000	4,384.50000	[illegible]204
40	1,047.00000	5,528.20000	[illegible]55

76. The efficiency of a system of electric wiring depends on the amount of power that is consumed in heating the wires instead of being conveyed to the lamps or other transforming devices. This loss of power (in watts) is equal to the volts *drop* in the line multiplied by the *current* in *amperes*. Wiring specifications usually call for so many volts drop or not more than a certain percentage of drop on the line between the lamps and the center of distribution and between the center of distribution and the point where the wires enter the building or where the dynamo is located.

CALCULATION OF LINE LOSSES DUE TO RESISTANCE.

77. We will now calculate the drop on the wires in the factory shown in Fig. 41, using the smallest wires permitted by the Underwriters. The distance from the dynamo *D* to the point marked *A*, which is the average distance that the current travels on the No. 6 wire, is 150 feet (allowing for risers to a ceiling 15 feet high). As there must be two wires, the total length of wire is 300 feet.

The resistance of 1,000 feet of No. 6 wire (Table V) is .39440 ohm; therefore, the resistance of 300 feet of No. 6 wire is $.3 \times .39440 = .11832$ ohm. This line carries 50 amperes. By Ohm's law, the drop is given by the following relation:

Drop in line (volts) = current in line × resistance of line;

hence, $$\text{Drop} = 50 \times .118 = 5.9 \text{ volts}.$$

The line from *A* to *B* carries current for 9 lamps, or 4.5 amperes. Its distance is 140 feet and the resistance of the No. 14 wire is 2.521 ohms per 1,000 feet; hence

$$\text{Drop} = 4.5 \times \frac{2 \times 140}{1{,}000} \times 2.521 = 3.1765 \text{ volts}$$

drop on the branch line of No. 14 wire.

The total drop from *D* to *B* will then be $5.9 + 3.18 = 9.08$ volts. This is 8.3 per cent. of 110 volts, altogether too much for such a plant as we have been considering.

The reason why such a large loss must not be permitted, in addition to the simple matter of economy of power, is that such a large falling off in voltage will greatly reduce the brightness of the lamps and poor service will result. The cost of power alone, however, is usually a sufficient reason to prohibit such great losses in the wiring.

78. The plant we are considering requires 50 amperes at 110 volts, or 5,500 watts. This, if furnished by a lighting company, will cost between 10 cents and 20 cents a kilowatt-hour, at the rates ordinarily charged. That will be from $.55 to $1.10 an hour for light. 8.3 per cent. of this is 4.565 cents to 9.13 cents an hour. If the lights are used an average of 2 hours a day 300 days a year, this will amount to from $27.39 to $54.78 a year. If the loss were one-fourth as great, the saving in the cost of light in one year would more than pay for the additional cost of wire.

It is usual to specify a 2-per-cent. drop for such installations as this when the current is to be purchased at fairly high prices, and a 3-per-cent. to 5-per-cent. drop where the current is produced cheaply, as by a dynamo on the premises. Not more than a 5-per cent. drop should be permitted on short distances, even where very cheap work is desired. This would be accomplished in this case by using No. 4 wire for the feeders and No. 12 for the branch lines. The student may calculate the loss exactly by the use of Table V.

79. Drop in Arc-Light Wiring.—The loss on the arc lines using No. 10 wire from the point *A* is found as follows: The resistance of No. 10 wire is about 1 ohm per 1,000 feet.

$$\text{Drop from } A \text{ to lamp No. } 3 = 15 \text{ (amperes)} \times \frac{2 \times 10 \text{ (feet)}}{1{,}000} = .3 \text{ volt;}$$

$$\text{Drop from lamp No. } 2 \text{ to lamp No. } 3 = 10 \times \frac{2 \times 50}{1{,}000} = 1 \text{ volt;}$$

$$\text{Drop from lamp No. } 1 \text{ to lamp No. } 2 = 5 \times \frac{2 \times 50}{1{,}000} = .5 \text{ volt;}$$

Drop from lamp No. *4* to lamp No. *5* = .5 volt;

Drop from *A* to lamp No. *4* = $10 \times \frac{2 \times 40}{1,000} = .8.$

Total drop at lamp No. *1* = .3 + 1 + .5 = 1.8 volts;
Total drop at lamp No. *2* = .3 + 1 = 1.3 volts;
Total drop at lamp No. *3* = .3 volt;
Total drop at lamp No. *4* = .8 volt;
Total drop at lamp No. *5* = .8 + .5 = 1.3 volts.

These slight variations can be permitted on the arc lamps without inconvenience.

80. Size of Wire for Arc Lights.—It should be noted that No. 10 wire is the smallest permitted on this line if the line is protected by but one cut-out. But if the line is divided into two parts, one for lamps Nos. *1*, *2*, and *3* and

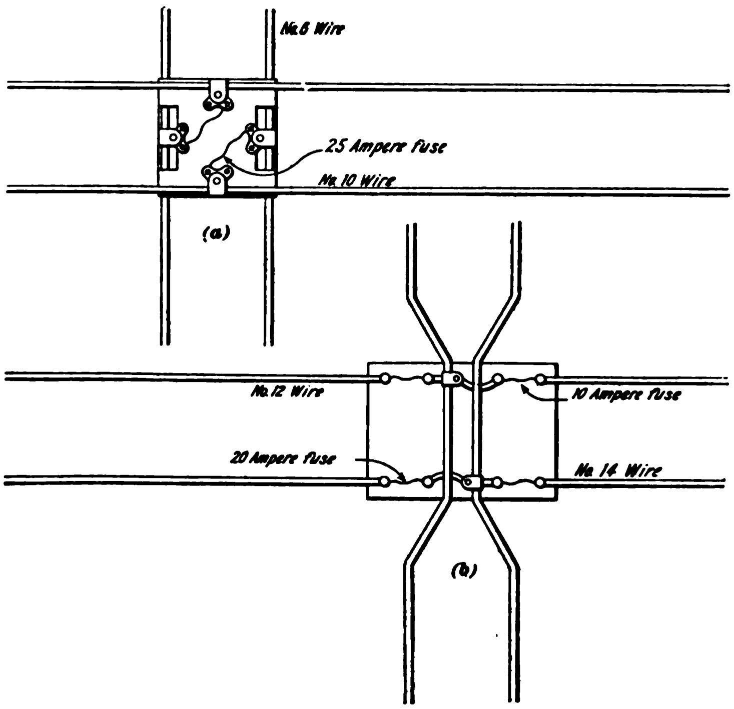


FIG. 42.

one for lamps Nos. *4* and *5*, with separate cut-outs for each of these lines, smaller wires may be used, so far as the Underwriters' rules are concerned. Fig. 42 shows the sizes permitted (*a*) with a single branch block and (*b*) with a double branch block.

The wires that have their sizes designated by odd numbers from No. 7 up are not usually manufactured for line work and cannot be purchased except on special order. Therefore, work must be done without using Nos. 7, 9, 11, and 13. The resistances of these sizes, however, are given in the table, and these wires are extensively used in the manufacture of electrical machinery. In tables given later, the above sizes are not given, although in a number of cases they would come nearer the calculated size. In interior wiring, it does not, as a rule, pay to split hairs over the sizes of wire, and the nuisance of carrying a large number of sizes of wire in stock more than counterbalances any slight gain there might be in the copper used on a given job. For this reason, the above odd sizes are not generally used. Moreover, the tendency is always to add more lights to a system, and it is best to be liberal when installing the wire.

CALCULATION OF THE PROPER SIZE OF WIRE FOR A GIVEN LOSS.

81. Wiring for 110 Volts, 2-Per-Cent. Drop.—We will now calculate the sizes of wires required in the building wired according to Fig. 41 for a loss of 2 per cent. (2 per cent. of 110 = 2.2 volts).

This calculation will be made with a view to making the drop uniform along all the lines. That is, we will make the volts drop per foot of line equal as nearly as possible in feeders and branches. The proper value of volts drop per foot is found by allowing the desired drop to the farthest lamp in the system and distributing this drop uniformly along the lines to the generator, or center of distribution.

The average distance from the dynamo to the farthest lamps is 150 + 140 = 290 feet. This requires 580 lineal feet of wire, or .580 thousand feet, there being two lines.

$$\frac{2.2 \text{ (volts)}}{.580} = 3.8 \text{ volts per } 1{,}000 \text{ ft.}$$

3.8 (volts) ÷ 50 (amperes) = .076 ohm per 1,000 ft. for mains

The nearest wire to this is No. 00, with .078 ohm per 1,000 feet. Using this, the loss on the mains will be .3 × .078 × 50 = 1.17 volts, leaving 2.2 − 1.17 = 1.03 volts to be lost in the distribution lines and 1.03 ÷ .28 = 3.68 volts per 1,000 feet in the branch lines. The wire nearest to this is No. 9.

The student will see at once that in making a saving of about 7 per cent. (9.13 − 2.2 volts) in efficiency he has been obliged to use about five times as much copper, and that if the distances are long and the losses must be small, the cost of wire will prohibit the use of low voltages.

82. Wiring for 220 Volts, 3-Per-Cent. Drop.—As a further exercise in calculating the required sizes of wires in terms of resistances per 1,000 feet, let us ascertain the proper sizes of wire to equip the factory with 220-volt lamps, allowing 3 per cent. loss.

As 220-volt lamps are not as efficient as 110-volt lamps, we will allow 60 watts per 16-candlepower lamp and 3 amperes per enclosed-arc lamp. The four circuits for incandescent lamps carry approximately equal loads and are of about the same length, so that if we calculate the size of wire to use on one of them, we will have found the proper size for them all.

10 (lamps) × 60 (watts per lamp) ÷ 220 (volts) = 2.73 amperes.

$$\begin{aligned} 4 \times 2.73 &= 10.92 \text{ amperes for incandescent lamps.} \\ 5 \times 3.00 &= \underline{15.00} \text{ amperes for arc lamps.} \\ & 25.92 \text{ amperes total current.} \end{aligned}$$

3 per cent. of 220 volts is 6.6 volts.

$$\frac{6.6}{.580} = 11.38 \text{ volts lost per 1,000 feet;}$$

$$\frac{11.38}{25.9} = .44 \text{ ohm per 1,000 feet for the mains.}$$

The wire with resistance nearest this is No. 6, with .394 ohm per 1,000 feet. Using this size, we will have a loss on the mains of $.3 \times .394 \times 25.9 = 3.07$ volts, leaving 3.53 volts to be lost on branch lines.

The size of these branch lines will, therefore, be found as follows:

$\frac{3.53}{.28}$ = volts drop per 1,000 feet in branch lines and $\frac{3.53}{.28} \div 2.73$ = 4.62 ohms per 1,000 feet.

Table V gives 4.009 ohms per 1,000 feet for No. 16 wire, which is smaller than the Underwriters will permit. No. 14 must be used, even though it is larger than necessary as far as the drop is concerned. The loss will then be on the branch line $.28 \times 2.526 \times 2.73 = 1.93$ volts, leaving $6.60 - 1.93 = 4.67$ volts to be lost in the mains, instead of 3.07, as previously calculated.

$$\frac{4.67}{.3} \div 25.9 = .6 \text{ ohm per 1,000 feet in feeders.}$$

No. 8 wire has .627 ohm per 1,000 feet and is nearest the required size.

In 220-volt wiring, where the distances within the building are short, the wireman will usually find that the minimum sizes of wires specified by the Underwriters are large enough to carry the current with less than 2 per cent. loss. In small dwellings wired on the closet system of distribution with 220-volt circuits, it will not be necessary to pay any attention whatever to the drop on inside lines.

83. Center of Distribution.—In making calculations relating to wiring, the distance to be taken is the *average distance* through which the current supplied can be considered as flowing. For example, take a case like that shown in Fig. 43, where a circuit is run from a distributing point *A* to a number of lamps *B*. For the first 100 feet no lamps are connected; we then have, say, 12 lamps spread out over 50 feet at the end. In calculating the drop on such a circuit, it is evident that the full length should not be taken, because the whole of the current does not flow through all the line. The current keeps decreasing as each lamp is passed. The center of distribution for the lamps will, therefore, be at *C* and the average length of wire through which the 6 amperes is carried is 2 × 125 = 250 feet. If the lights were all bunched at the end of the line, the distance to the center of distribution would then be the same as the length of the line, and the length of wire through which the 6 amperes would flow would be 2 × 150 = 300 feet. If the lights were spaced uniformly throughout the whole length of the line, the average distance would then be $\frac{150}{2} = 75$ feet and the average length of wire used in making calculations for drop would be 150 feet. By laying out a plan of the wiring, the average distance over which the current is transmitted can usually be determined without much trouble and close enough for practical purposes.

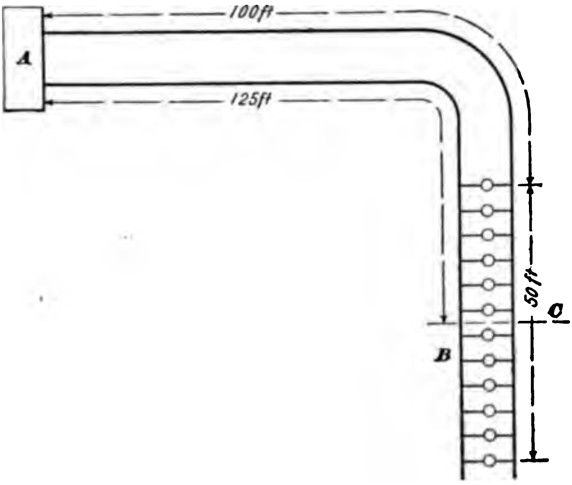


FIG. 43.

EFFECT OF CONNECTING LOW-VOLTAGE CURRENT AND LAMPS TO WIRING CALCULATED FOR HIGH VOLTAGE.

84. The percentage of drop on any system of wiring is inversely proportional to the square of the voltage, if the watts transmitted are the same. That is, if we have 1 watt lost in transmitting 100 watts at 220 volts over a certain wire, we will have 4 watts lost in transmitting 100 watts at 110 volts over the same resistance, and 16 volts lost in transmitting at 55 volts. Let us see what would be the result if the factory wired for 220 volts, 3 per cent. loss, were connected to 52-volt supply wires and furnished with 52-volt lamps.

40 52-volt lamps taking 1 ampere each, 40 amperes.
5 alternating arc lamps.............. 50 amperes.
Total current.................. 90 amperes.

.627 × .3 × 90 = 16.93 volts lost in mains.
2.53 × .28 × 10 = 7.08 volts lost in branches.
Total = 24.01 volts lost in wiring.

The actual volts drop will not be as great as this because the current will not be as great, owing to the resistance of the lines; for the lamps being supplied with considerably less than 52 volts will not take their full amount of current. These figures will be correct, however, if the lamps take 1 ampere each (as would 25-volt 8-candlepower lamps if they were substituted for the 52-volt 16-candlepower lamps). Here, then, is a loss of about 50 per cent. and a reduction of the power transmitted of 50 per cent. Leaving the 52-volt lamps in place, the actual voltage will be (since the resistance of the lines is about equal to one-half that of the lamps, or one-third the total resistance) about 35 volts. The main lines, moreover, will not carry a current of 60 amperes safely.

85. Selection of Fittings for 220-Volt Wiring.—In 220-volt wiring great care must be taken in the selection of fittings. Cut-outs, sockets, and switches designed for 110-volt working and not improved during recent years so as to comply with the severer requirements of the present day must not be used on higher voltages. Keyless sockets should be used for 220-volt work and the lamps controlled by switches; no rosettes with fuses should be installed, fuses being placed in approved cut-outs, one of which should be provided for each ten lamps or less. If proper precautions are taken to procure good cut-outs, sockets, and switches, there is no especial difficulty to be encountered in 220-volt work, though the lamps are not as efficient as can be procured for lower voltages.

Fig. 44 (*a*) and (*b*) shows two cut-outs designed especially for 220-volt work. The construction is such as to secure higher insulation and less liability to arcing than with the ordinary 110-volt fittings. Fig. 44 (*a*) is a three-wire branch block shown without the fuses in place. Fig. 44 (*b*) is a three-wire main block with the fuses *f* in their proper position. These fuses are of the enclosed type; i. e., the fuse is enclosed in an insulating holder that, in this case, is held by clips *g*, *g*, (*a*).

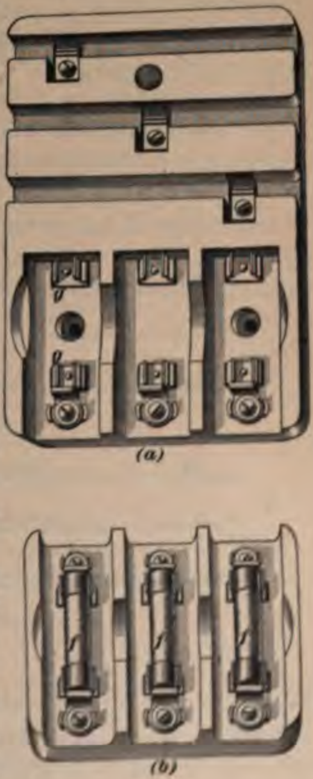


FIG. 44.

Enclosed fuses have of late years become quite common. The idea is to prevent the fuse arcing when it blows and also to protect it. It is claimed that enclosed fuses are more reliable than open ones, because they may be depended on to blow more nearly at their rated current. Open fuses often come in contact with the cold porcelain base, and this has a marked influence on their fusing point. Drafts of air may also influence the fusing point considerably. Enclosed fuses are now very generally used for 110-, 220-, and 500-volt work.

86. Size of Wire for Three-Wire System.—If it is desired to wire the shop which we have been considering for 110-volt lamps on the Edison three-wire system, the sizes of the main wires required will be the same as for the 220-volt two-wire system, and a third, or neutral, wire must be installed. This is usually placed between the other two, and if the wires are put upon cleats, three-wire cleats may be used. The neutral wire must not be smaller than will be required for the safe carrying capacity for the current of all the lamps on one side of the circuit. In this case, that current is 25 amperes and the wire must not be smaller than No. 10. It should be larger, to prevent unbalancing when lamps are turned off.

87. Unbalancing of Three-Wire System.—The unbalancing of a three-wire system with the three wires of equal size is illustrated in Fig. 45 (*a*) and (*b*). When the system is balanced as in (*a*), we have 3 amperes in the outside wires and no current in the neutral. We will take the pressure between *A* and *C* or *C* and *E* as 112 volts, and between *B* and *D* or *D* and *F* as 110 volts. There is, therefore, a drop of 2 volts in *A B* and also a drop of 2 volts in *E F*. The

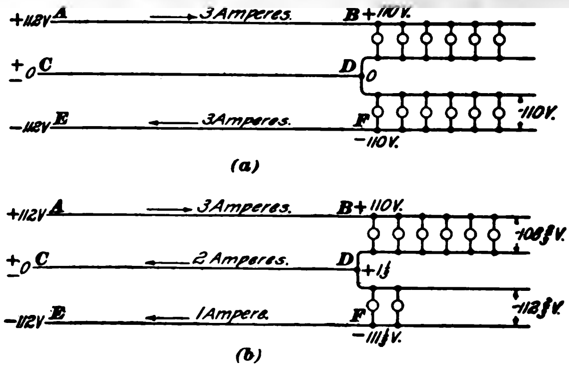


FIG. 45.

resistance of *A B*, *C D*, and *E F* must, therefore, be $\frac{2}{3}$ ohm, in order to give a drop of 2 volts with a current of 3 amperes. If the load becomes unbalanced, as in (*b*), there will be a current of 3 amperes in *A B*, as before, 2 amperes in *C D*, and 1 ampere in *E F*. The drop in *A B* will be $\frac{2}{3} \times 3 = 2$ volts; in *C D*, $\frac{2}{3} \times 2 = 1\frac{1}{3}$ volts; in *E F*, $\frac{2}{3} \times 1 = \frac{2}{3}$ volt. The total drop in the two outside wires will now be $2 + \frac{2}{3} = 2\frac{2}{3}$ volts, and hence the pressure between the outside wires at the end of the line must be $224 - 2\frac{2}{3} = 221\frac{1}{3}$ volts. Taking the upper side of the circuit, we have 3 amperes flowing out through *A B* and 2 amperes flowing back through *C D*; the drop on this side must, therefore, be $2 + 1\frac{1}{3} = 3\frac{1}{3}$ volts and the pressure between *B* and *D* must be $112 - 3\frac{1}{3} = 108\frac{2}{3}$ volts. The pressure between *B* and *F* is $221\frac{1}{3}$ volts; hence, the pressure between *D* and *F* must be $221\frac{1}{3} - 108\frac{2}{3} = 112\frac{2}{3}$. The result of the uneven load is, therefore, that the voltage rises in the lightly loaded side and falls on the side having a heavy load. If the neutral wire were smaller, this unbalancing would be greater.

The branch lines of a three-wire system must be calculated for the proper current and drop on 110 volts as two-wire circuits, because these branches are simple two-wire circuits.

INTERIOR WIRING.

(PART 2.)

UNIFORM DROP IN FEEDER LINES.

1. In installations where there are many sets of feeder lines running to various departments, it is usual to allow a certain loss in the feeders and a certain other loss in the distribution wires. The loss in all feeders is made the same, and the dynamo is operated at a higher voltage than the lamps will stand, with the intention of losing a definite amount before the lamps are reached. It is important that the voltage at the lamps should never exceed that for which they are intended.

2. Fig. 1 represents a factory, such as a wagon works or furniture factory. Only the outlines of the buildings are indicated. The dynamo and switchboard are located at *D* in the engine room. The various centers of distribution are to be at or near the centers of the various floors. A separate pair of mains is to be run to each distribution center. Where elevator shafts are convenient, they are used to run risers to the upper floors. In the case illustrated there are fourteen pairs of feeder wires, each pair being represented by one line in the figure.

A 115-volt dynamo and 110-volt lamps are to be used. A loss of 2 volts is to be allowed in the distribution wires and

For notice of copyright, see page immediately following the title page.

a loss of 3 volts in the feeders, irrespective of their length. The figure shows the plan of the feeders on one floor only; the small round dots indicate risers.

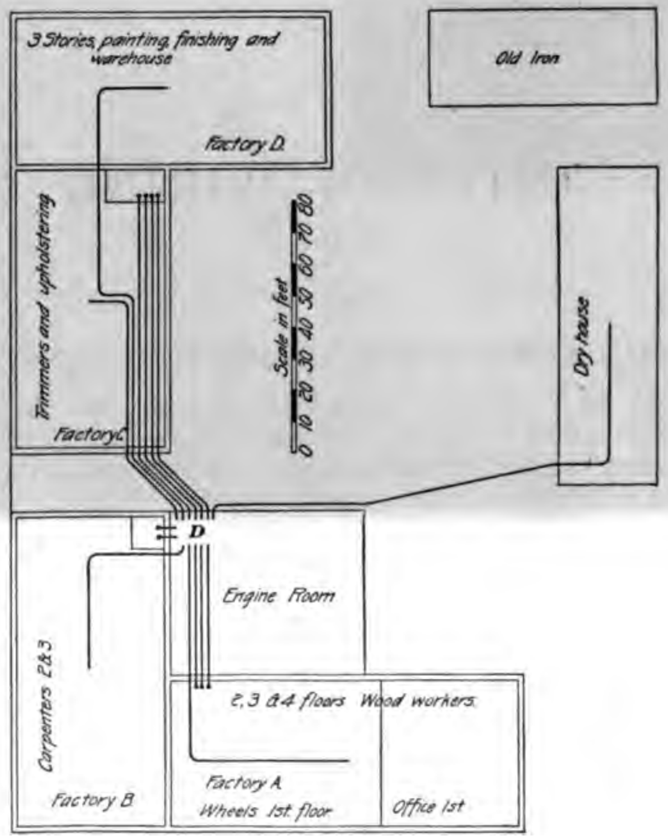


FIG. 1.

We will calculate the feeders on one floor only.

	Lamps.	*Amperes.*	*Distance.*	*Length of Wire.*
Shop *A*,	50	25	130 ft.	**260 ft.**
Shop *B*,	40	20	75 ft.	**150 ft.**
Shop *C*,	40	20	85 ft.	**170 ft.**
Shop *D*,	40	20	175 ft.	**350 ft.**

The resistance per 1,000 feet of these feeders required to give a drop of 3 volts and the nearest sizes of wires obtainable, are calculated as follows:

Shop *A*, $\frac{3}{25 \times .26} = .461$, No. 6 has .395 ohm per 1,000 feet.

Shop *B*, $\frac{3}{20 \times .15} = 1.000$, No. 10 has .999 ohm per 1,000 feet.

Shop *C*, $\frac{3}{20 \times .17} = .882$, No. 10 has .999 ohm per 1,000 feet.

Shop *D*, $\frac{3}{20 \times .35} = .429$, No. 6 has .395 ohm per 1,000 feet.

3. This method of calculating required sizes of wires can be applied to any kind of wiring for any practical purpose; but to avoid the necessity of figuring out each case, wiring tables have been prepared by which the proper size can be determined without calculation.

CALCULATION OF WIRE SIZES IN TERMS OF RESISTANCE PER 1,000 FEET.

4. Calculations based on resistance per 1,000 feet, such as have been made in previous examples, may be put in the shape of a formula as follows:

$$r_m = \frac{e \times 1,000}{2 \times D \times C}, \qquad (1.)$$

in which r_m is the resistance of 1,000 feet of the wire to be used, e the drop in volts, D the distance measured in feet, and C the current measured in amperes.

For example, to carry 10 amperes 600 feet ($600 \times 2 = 1,200$ feet of wire) with 3 volts drop, the resistance per 1,000 feet will be:

$$r_m = \frac{3 \times 1,000}{2 \times 600 \times 10} = .250 \text{ ohm per 1,000 feet.}$$

No. 4 wire has about this resistance, as may be seen by consulting a wire table.

TABLE I.

Amperes.	Distances in Feet for Loss of 1 Volt.																
	20	25	30	35	40	45	50	60	70	80	90	100	120	140	160	180	200
1														14	14	14	14
1.5												14	14	12	12	12	12
2									14	14	14	14	12	12	12	10	10
3							14	14	12	12	12	12	10	10	10	8	8
4						14	14	12	12	12	10	10	10	8	8	8	8
5				14	14	12	12	12	10	10	10	10	8	8	8	6	6
6			14	12	12	12	12	10	10	10	8	8	8	6	6	6	6
7		14	12	12	12	12	10	10	10	8	8	8	6	6	6	6	5
8		14	12	12	10	10	10	10	8	8	8	8	6	6	6	5	5
9	14	12	12	12	10	10	10	8	8	8	8	6	6	6	5	4	4
10	14	12	12	10	10	10	10	8	8	8	6	6	6	5	5	4	4
12	12	12	10	10	10	8	8	8	6	6	6	6	5	4	4	3	3
14	12	10	10	10	8	8	8	6	6	6	6	5	4	4	3	3	2
16	12	10	10	8	8	8	8	6	6	5	5	5	4	3	3	2	2
18	10	10	8	8	8	8	6	6	6	5	5	4	3	3	2		
20	10	10	8	8	8	6	6	6	5	5	4	4	3	2	2		
25	10	8	8	6	6	6	6	5	4	4	3	3	2				
30	8	8	6	6	6	5	5	4	3	3	2	2					
35	8	6	6	6	5	5	4	3	3	2	2						
40	8	6	6	5	5	4	4	3	2	2							
45	6	6	5	5	4	4	3	2	2								
50	6	6	5	4	4	3	3	2									
55	6	5	4	4	3	3	2	2									
60	6	5	4	3	3	2	2										
65	6	5	4	3	3	2	2										
70	5	4	3	3	2	2											
75	5	4	3	2	2												
80	5	4	3	2	2												
90	4	3	2	2													
100	4	3	2														

Size Wire in B. & S. Gauge, Soft Copper.

5. Wiring Table Giving Distances for Drop of 1 Volt. In Table I, distances in feet are given in the top horizontal line. Beneath these distances are columns containing numbers that designate the proper size of wire to use to obtain a drop of 1 volt when the wire carries the current given in the corresponding line in the left-hand column.

If it is desired, for example, to find the size of wire necessary to get a loss of not more than 1 volt with 20 amperes, and a distance of 140 feet (i. e., two wires, 140 feet long, side by side), we look under 140 and to the right of 20 and find the figure 2. No. 2 wire will be required. If it is desired to find the wire required for a loss of 2 volts with 20 amperes and a distance of 140 feet, we may divide the distance by the loss in volts and use the table as before; i. e., under 70 and to the right of 20 is found 5. No. 5 is the proper wire. Or, we may use the distance given and divide the current by the number of volts; i. e., under 140 and to the right of 10 is found 5. The table is sufficiently accurate for all practical purposes. Where very great exactness is desired, it is better to calculate the lines. For the smaller sizes in this table, the nearest even sizes of wire are given because the odd sizes are not ordinarily used.

CALCULATION OF WIRES IN TERMS OF CIRCULAR MILS.

6. In the table of Safe Carrying Capacities (Part 1), the wires are listed both by number (B. & S. gauge) and by **circular mils.** Cables having no B. & S. gauge number are listed by circular mils only. Large cables of any desired cross-section in circular mils are made to order by all the leading manufacturers of insulated wires.

It is often more convenient to calculate the size of wires or cables in terms of circular mils than in terms of resistance per 1,000 feet; and calculations in terms of circular mils are applicable to wires or cables of any size or shape. A **mil** is another name for $\frac{1}{1000}$ inch.

A round wire 1 mil in diameter has a cross-section of

1 circular mil. A copper wire 1 mil ($\frac{1}{1000}$ inch) in diameter and 1 foot long (1 **mil-foot**) has a resistance of 10.8 ohms; or, 1 *mil-foot of pure copper has 10.8 ohms resistance at 75° F.*

A wire 2 mils in diameter has a section of 4 circular mils (abbreviated 4 C. M.); 3 mils in diameter, 9 circular mils; 4 mils, 16 circular mils; 5 mils, 25 circular mils; x mils, x^2 circular mils. *The circular mils cross-section of any round wire is equal to the square of its diameter in mils.* The circular mils of any conductor of other shape are equal to its area in *square mils* multiplied by 1.273 or divided by .7854. For instance, the circular mils of 0000 wire (diam. $= 460$ mils) $= 460^2 = 211,600$ circular mils, while a bar of copper $\frac{1}{4}$ inch by $\frac{1}{2}$ inch (250 mils by 500 mils) has a section of $250 \times 500 = 125,000$ square mils or $250 \times 500 \times 1.273 = 159,125$ circular mils.

7. If the length in feet of a wire is known and also its area in circular mils, the resistance may at once be determined by the formula

$$R = \frac{L \times 10.8}{\text{cir. mils}}. \qquad (2.)$$

In this formula, L must be the total length of wire in *feet*.

Also, since the drop e in a circuit is equal to the current C × resistance R, we have

$$\text{Drop } e = \frac{C \times L \times 10.8}{\text{cir. mils}}; \qquad (3.)$$

or if the drop is given and we are required to find the size of wire to give this drop, we may put formula **3** in the form

$$\text{Cir. mils} = \frac{C \times L \times 10.8}{e}. \qquad (4.)$$

In these formulas L is the total length of the circuit, i. e., the distance to the lamps and back again. If the distance to the lamps, one way, is called D, we may put formula **4** in the form

$$\text{Cir. mils} = \frac{21.6 \times C \times D}{e}. \qquad (5.)$$

8. This last formula will generally be found as useful as any that can be given for interior-wiring calculations. It will be well to commit it to memory, because one does not always have a wiring table at hand when calculations are to be made and, besides, calculations have often to be made that are beyond the range of the tables. It can be applied to any two-wire system or to the three-wire system, as illustrated by the following examples:

EXAMPLE 1.—By means of formula **5**, calculate the size of wire necessary to supply 80 16 c. p. lamps situated at a distance of 200 feet from the center of distribution. The allowable drop is to be 3 volts.

SOLUTION.—We have $D = 200$ and $e = 3$. Each 16-candlepower lamp will take about ½ ampere; hence, $C = 40$.

$$\text{Cir. mils} = \frac{21.6 \times 200 \times 40}{3} = 57{,}600,$$

or between No. 2 and No. 3 B. & S. No. 2 wire would likely be used.

EXAMPLE 2.—Calculate the size of wire necessary to supply 100 lamps on a 110–220-volt three-wire system. The distance from the center of distribution to the lamps is 250 feet and the drop on each side of the system is not to exceed 3 volts. The lights are supposed to be balanced, 50 lamps on each side.

SOLUTION.—The simplest method of solving this problem is to treat it as if it were a two-wire system and use formula **5**. Each pair of lamps will take ½ ampere; hence, the current in the outside wires, when all the lamps are burning, will be $\frac{100}{4} = 25$ amperes instead of $\frac{100}{2} = 50$ amperes, as it would have been if a two-wire system were used. The allowable drop on each side of the circuit is 3 volts; hence, the total drop in the outside wires will be 6 volts. We have, then,

$$\text{Cir. mils} = \frac{21.6 \times 25 \times 250}{6} = 22{,}500.$$

A No. 6 wire will be large enough and also would most likely be installed for the neutral.

The same method may be used for a 220–440-volt three-wire system, except that in estimating the current, allow about .3 ampere for each *pair* of lamps instead of .5 ampere, as in the previous case.

9. Estimation of Current Required by Lamps.—As previously mentioned, it is customary in estimating the current taken by lamps to allow about ½ ampere for each

TABLE II.

DISTANCE IN FEET PRODUCING A DROP OF 1 VOLT FOR GIVEN CURRENTS AND GIVEN SIZES OF WIRE.

	Amperes.	1	2	3	4	5	6	7	8	9	10	12	15	18	20	25	30	35	40	45	55	65	75	85	95	100
Size of Wire, B. & S. Gauge.	18	75.2	37.6	25.1	18.8	15.0																				
	16	120.0	60.0	40.0	30.0	24.0	20.0																			
	14	190.0	95.0	63.3	47.5	38.0	31.7	27.1	23.8	21.1	19.0	15.8	12.7													
	12	302.0	151.0	101.0	75.5	60.4	50.3	43.1	37.7	33.6	30.2	25.2	20.2	16.8	15.1											
	10	480.0	240.0	160.0	120.0	96.0	80.0	68.6	60.0	53.3	48.0	40.0	32.0	26.7	24.0	19.2	16.0	13.7								
	8	764.0	382.0	255.0	191.0	153.0	127.0	109.0	95.5	84.9	76.4	63.7	51.0	42.5	38.3	30.6	25.5	21.8	19.1	17.0						
	6	1,215.0	607.0	405.0	304.0	243.0	202.0	174.0	152.0	135.0	121.0	101.0	81.0	67.5	60.8	48.6	40.5	34.7	30.4	27.0	22.1					
	5	1,533.0	766.0	511.0	383.0	307.0	255.0	219.0	192.0	170.0	153.0	128.0	102.0	85.0	76.6	61.3	51.1	43.8	38.4	34.1	27.8	23.6	20.4			
	4	1,933.0	966.0	644.0	483.0	387.0	322.0	276.0	242.0	215.0	193.0	161.0	129.0	107.0	96.7	77.3	64.4	55.1	48.3	43.0	35.1	29.7	25.8	22.7		
	3	2,437.0	1,219.0	812.0	609.0	487.0	406.0	348.0	305.0	271.0	244.0	203.0	162.0	135.0	122.0	97.4	81.1	69.6	60.9	54.0	44.3	37.5	32.5	28.7	25.7	24.4
	2			1,024.0	768.0	615.0	512.0	439.0	384.0	341.0	307.0	257.0	205.0	171.0	154.0	123.0	102.0	87.9	76.9	68.3	55.9	47.3	41.0	36.2	32.4	30.7
	1			1,291.0	969.0	775.0	646.0	554.0	484.0	431.0	387.0	323.0	258.0	215.0	194.0	155.0	129.0	111.0	96.9	86.0	70.3	59.6	51.7	45.6	40.8	38.7
	0				1,222.0	978.0	815.0	698.0	611.0	543.0	489.0	407.0	326.0	272.0	245.0	195.0	163.0	140.0	122.0	109.0	88.7	75.2	65.1	57.5	51.4	48.9
	00					1,232.0	1,027.0	880.0	770.0	685.0	616.0	513.0	410.0	342.0	308.0	246.0	205.0	176.0	154.0	137.0	112.0	94.8	820.0	72.5	64.8	61.6
	000						1,295.0	1,110.0	971.0	863.0	777.0	648.0	518.0	432.0	388.0	311.0	259.0	222.0	194.0	173.0	141.0	119.0	104.0	91.4	81.7	77.7
	0000							1,400.0	1,225.0	1,089.0	980.0	817.0	653.0	544.0	490.0	392.0	326.0	280.0	245.0	218.0	178.0	151.0	131.0	115.0	103.0	98.0

Distance in Feet.

Table II is very convenient because it gives the distance exactly corresponding to the required drop. To use it, divide the number of amperes transmitted by the number of volts drop desired. Find the nearest number to this result in the line of amperes; below this find the distance in feet most nearly corresponding to the given distance; to the left of this, in the column of wire sizes, is given the number of the required wire.

For example, to find the size of wire to transmit 15 amperes 140 feet with 3 volts loss, divide 15 by 3 and find the quotient 5 in the line of amperes. In the column below, we find the nearest distance 153, and to the left of this the size of wire required, No. 8.

13. Probably the most convenient of all methods of calculation, after one is accustomed to using it, is the graphical method, in which amperes and distances are laid off at right angles to one another, and the wires corresponding to different values of these quantities, for the loss of 1 volt, are represented by curved lines. Figs. 2 and 3 are diagrams of this kind. Notice that every wire curve is dotted for a short distance for currents larger than the maximum allowed by the Underwriters' rules for that size of wire. In determining the size of wire from these diagrams, do not use the dotted portions of the curves. If a point should come near one of the dotted sections, use the next larger size of wire.

To use such a diagram, find the point where the lines representing amperes and given distance intersect, and take the wire indicated by the wire line nearest this point. Unless the wire line is very close, take the larger wire of the two lines on each side of the intersection point.

For example, to find the wire required for 7 volts loss in a distance of 125 feet, with 21 amperes, we divide 21 by 7, which gives 3; where the line of 3 amperes intersects the line of 125 feet, we are between the lines representing No. 10 and No. 12 wire. The point lies about midway between the two curves, and hence we use the larger size of wire, No. 10.

14. In calculating the sizes of wires for 52-, 104-, 220-, or 250-volt work, or for any intermediate voltage, it must

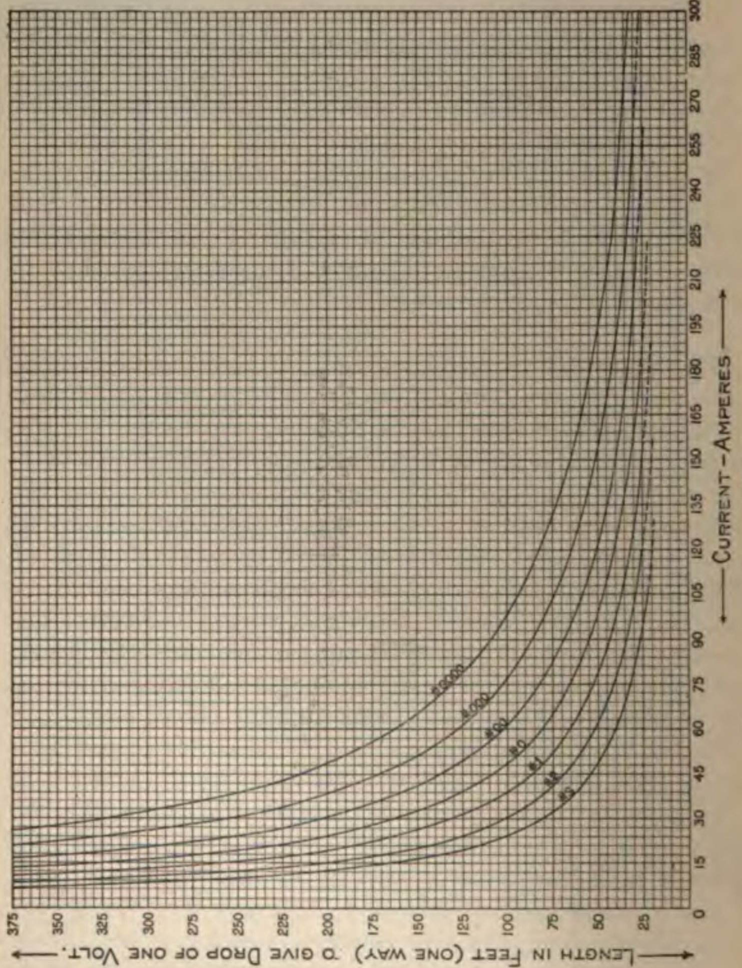


FIG. 9

be borne in mind that lamps burning on lower voltages than 110 take more current, and those burning on higher voltages take less current. An ampere per lamp for 52-volt lamps, ½ ampere per lamp for 104- or 110-volt lamps, and

.3 ampere per lamp for 220-volt lamps is a safe basis for calculations where good lamps are used. Also, it must be

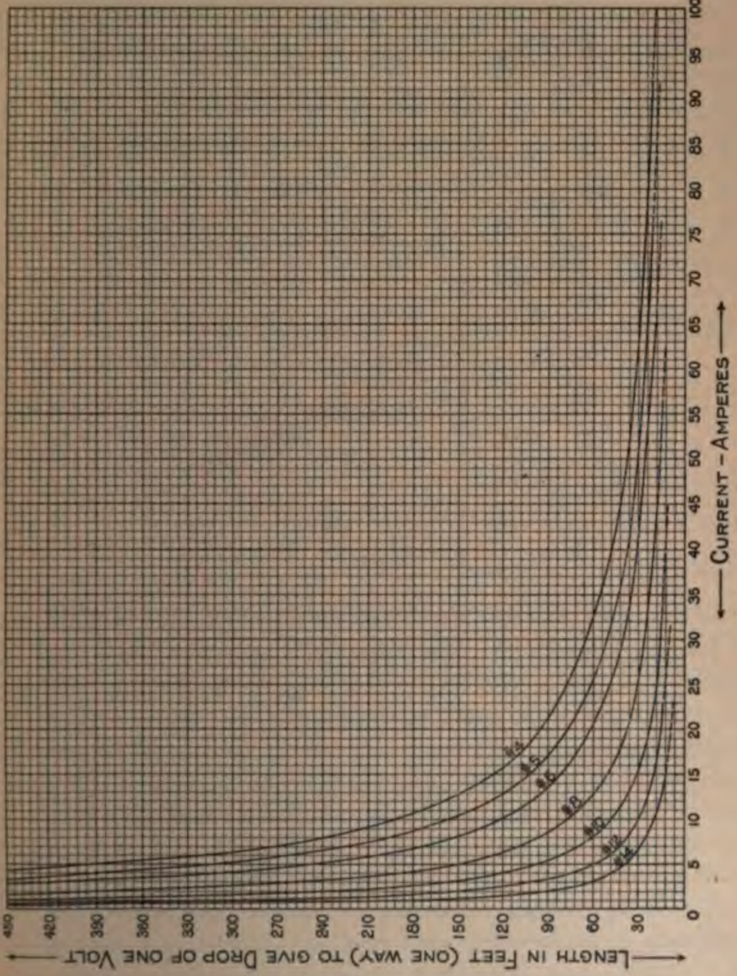


FIG. 3.

remembered that "per cent. drop" and "volts drop" are very different things, as set down in Table III.

The figures given in the table represent the actual drop in volts for the line voltage at the top of each column, with the percentages of drop given in the left-hand column. For example, a drop of 5 per cent. on a voltage of 150 would give 7.5 volts.

TABLE III.

Per Cent. Drop.	Line Voltages.					
	52	104	110	150	220	250
1	.52	1.04	1.1	1.5	2.2	2.5
2	1.04	2.08	2.2	3.0	4.4	5.0
3	1.56	3.12	3.3	4.5	6.6	7.5
5	2.60	5.20	5.5	7.5	11.0	12.5
7	3.64	7.28	7.7	10.5	15.4	17.5
10	5.20	10.40	11.0	15.0	22.0	25.0
15	7.80	15.60	16.5	22.5	33.0	37.5

FUSE PROTECTION FOR CONDUCTORS IN MULTIPLE.

15. It is frequently desirable to run two or more small wires in multiple, instead of one large wire or cable, either for convenience in handling the wires, to obtain a certain carrying capacity with the use of less copper, to use material that happens to be at hand, or for other reasons. When two or more wires are run thus and are connected together at their ends, separate fuses must be placed in series with each wire, and not one fuse for all the wires in multiple.

Fig. 4 (*a*) and (*b*) illustrates the correct and the incorrect methods of connecting such cables. Multiple conductors of this kind may sometimes be used to advantage in overhauling or remodeling old work, where the wires originally installed are too small, and in wiring an old building by the use of molding, where large wires cannot be handled without defacing the walls.

For convenience in comparing the conductivities of wires, Table IV is given. As an illustration, it is seen from the table that instead of a single No. 2 wire we might use four No. 6 wires; two No. 5; four No. 8; etc. Of course, nothing smaller than No. 14 can be used for interior wiring.

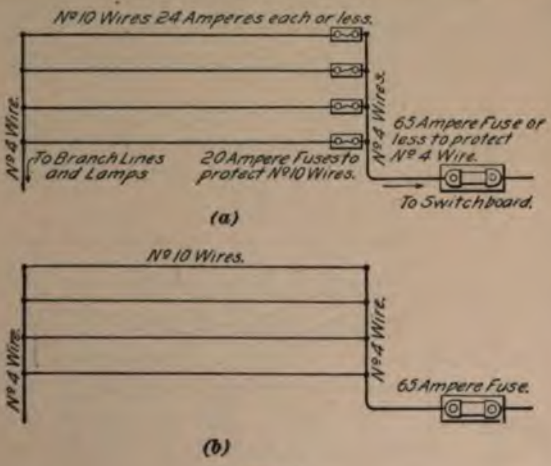

Nº 10 Wires 24 Amperes each or less.
Nº 4 Wire.
To Branch Lines and Lamps
20 Ampere Fuses to protect Nº 10 Wires.
Nº 4 Wires.
65 Ampere Fuse or less to protect Nº 4 Wire.
To Switchboard.
(a)
Nº 10 Wires.
Nº 4 Wire.
Nº 4 Wire.
65 Ampere Fuse.
(b)

FIG. 4.

The conductivity is directly proportional to the total cross-section of all the conductors in multiple, and the total resistance is inversely proportional to the total cross-section.

16. Circuits of several wires in multiple are sometimes run where a large drop in voltage is not objectionable, but where a single wire small enough to produce that drop will not carry the current safely. Two or more small wires will safely carry more current than one large wire of equivalent cross-section, because two small wires have a greater surface area from which the heat can escape than has one wire of twice the cross-section. For instance, suppose it is desired to run wires in molding to secure a drop of 4 volts with 65 amperes over a distance of 100 feet. Calculating the required size of wire by means of Table II, we see that No. 5 will give the required drop. But No. 5 rubber-covered

Let us take another example. In an old building, wired with too much drop, it is desired to reenforce the mains so as to reduce the drop to 2 volts. A circuit of No. 8 wire carrying 20 amperes a distance of 200 feet is to be reenforced. What size of wire should be used?

Total resistance of the line should be $\frac{2}{20} = .1$ ohm. Since this line, whose resistance is to be .1 ohm, is 400 feet long both ways, then the resistance per 1,000 feet must be $.1 \times \frac{1000}{400} = .25$ ohm. The resistance of a No. 8 wire per 1,000 feet = .627 ohm. Let $r_1 = .627$ and $r_2 =$ the resistance per 1,000 feet of the wire required.

Then we have, by substituting in the formula $\frac{1}{R} = \frac{1}{r_1} + \frac{1}{r_2}$, $\frac{1}{.25} = \frac{1}{.627} + \frac{1}{r_2}$ or $\frac{1}{r_2} = \frac{1}{.25} - \frac{1}{.627} = 2.41$; hence, $r_2 = .415$.

A No. 6 wire of which the resistance is .394 ohm per 1,000 feet most nearly meets this requirement.

WIRING IN DAMP PLACES.

18. Where wiring is done in damp places, special precautions must be taken and special rules observed. The following Underwriters' rules apply to this work:

Wires—

In damp places, such as breweries, sugar houses, packing houses, stables, dye houses, paper or pulp mills, or buildings especially liable to moisture, or acid, or other fumes liable to injure the wires or their insulation, except where used for pendants:

a. Must have an *approved* rubber-insulating covering.

b. Must be rigidly supported on non-combustible, non-absorptive insulators that separate the wire at least 1 inch from the surface wired over, and wires must be kept apart at least 2½ inches for voltages up to 300 and 4 inches for higher voltages.

Rigid supporting requires under ordinary conditions, where wiring over flat surfaces, supports at least every 4½ feet. If the wires are liable to be disturbed, the distance between supports should be shortened. In buildings of mill construction, mains of No. 8 B. & S. wire or over, where not liable to be disturbed, may be separated about 4 inches, and run from timber to timber, not breaking around, and may be supported at each timber only.

c. Must have no joints or splices.

Sockets.—

a. In rooms where inflammable gases may exist, the incandescent lamp and socket must be enclosed in a vapor-tight globe and supported on a pipe hanger, wired with *approved* rubber-covered wire soldered directly to the circuit.

b. In damp or wet places or over specially inflammable stuff, waterproof sockets must be used.

When waterproof sockets are used, they should be hung by separate stranded rubber-covered wires, not smaller than No. 14 B. & S., which should preferably be twisted together when the drop is over 3 feet. These wires should be soldered direct to the circuit wires, but supported independently of them.

19. Fig. 5 shows a waterproof globe for use where inflammable gases may exist. In wiring damp cellars, it is especially desirable to have the lamps divided among several small circuits, so that the blowing of a fuse will not put out many lamps. In such work, rosettes should never be used, but the drop wires should be soldered direct to, but preferably not supported by, the line wires, and the joints should be thoroughly wrapped with insulating tape. The cut-outs should be placed outside the cellars, in a dry place if possible, otherwise they should be placed in waterproof boxes.

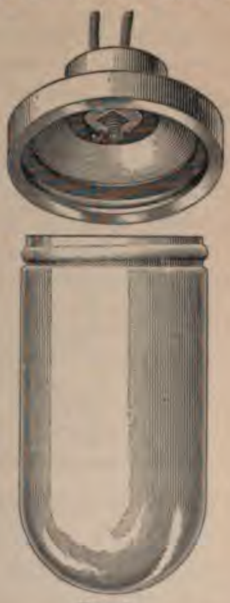


FIG. 5.

20. Rubber-Covered Wire.—*In all kinds of work, except open work in dry places, rubber-covered wire must be used.* The Underwriters require it to comply with the following specifications:

Rubber-Covered Wire.—

a. Copper for conductors must be thoroughly tinned.

Insulation for voltages between 0 and 600:

b. Must be of rubber or other approved substance and be of a thickness not less than that given in the following table for B. & S. gauge sizes:

From	18 to	16, inclusive,	$\frac{1}{32}$"
From	14 to	8, inclusive,	$\frac{3}{64}$"
From	7 to	2, inclusive,	$\frac{1}{16}$"
From	1 to	0000, inclusive,	$\frac{5}{64}$"
From	0000 to	500,000, C. M.	$\frac{3}{32}$"
From	500,000 to	1,000,000, C. M.	$\frac{7}{64}$"
Larger than		1,000,000, C. M.	$\frac{1}{8}$"

Measurements of insulating wall are to be made at the thinnest portion.

c. The completed coverings must show an insulation resistance of at least 100 megohms (100,000,000 ohms) per mile during 30 days' immersion in water at 70° F.

d. Each foot of the completed covering must show a dielectric strength sufficient to resist throughout 5 minutes the application of an electromotive force of 3,000 volts per $\frac{1}{64}$ inch thickness of insulation under the following conditions:

The source of alternating electromotive force shall be a transformer of at least 1 kilowatt capacity. The application of the electromotive force shall first be made at 4,000 volts for 5 minutes and then the voltage increased by steps of not over 3,000 volts, each held for 5 minutes, until the rupture of the insulation occurs. The tests for dielectric strength shall be made on a sample of wire that has been immersed for 72 hours in water, 1 foot of which is submerged in a conducting liquid held in a metal trough, one of the transformer terminals being connected to the copper of the wire and the other to the metal of the trough.

Tests by the Underwriters are made on the products of the various manufacturers from time to time, and the names of those wires that are acceptable, as complying with this standard, can be learned from them.

CONCEALED KNOB-AND-TUBE WORK.

21. The most common way of concealing wires in a building is to run them through the joists between the floors and ceilings and through studding partitions, and to insulate them by means of porcelain knobs and tubes, as shown in Fig. 6. The holes should not be closer together than is allowed by the Underwriters' rules, as given below, and the tubes should fit tightly in the holes. When the holes are not horizontal, but are bored from above or below obliquely, the tubes should be put in with their heads on the high side, so that they cannot fall or slide out; and when tubes are placed so that there is any strain upon them, their heads must be so placed that the tubes cannot slip. Holes should be bored of such a size that the tubes can be inserted by driving lightly. Do not make the holes too small or there will be danger of breaking the tubes. Holes must be bored sufficiently far away from the floors and ceilings to be out of reach of nails that may be driven into the joists after the work is concealed. Bushings must be long enough to reach all the way through the joists, with $\frac{1}{4}$-inch projection.

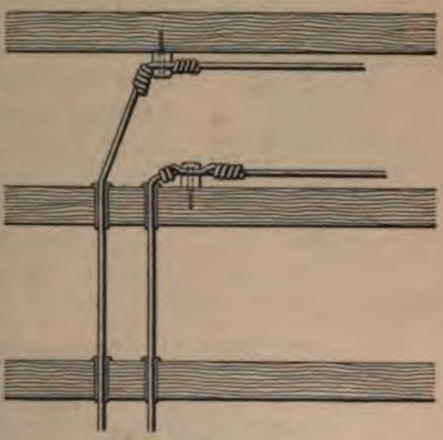


FIG. 6.

22. Where wires come through the plaster to outlets or cut-outs, they must be protected by proper bushings or outlet blocks. Special porcelain fittings have been designed for this purpose by several manufacturers. Careless work is often done at outlets, with the result that a job that is otherwise well put up will show poor insulation. The same outlets are very often used both for gas and electricity, and if the wires are not well protected when brought out, a ground on the gas pipe will result.

Fig. 7 shows the method of bringing out the wires when using curved, porcelain outlet tubes. The tubes are bound firmly to the gas pipe with tape and the curved ends hold the wire away from the pipe. Where there is no gas pipe, plain, straight tubes may be used if they are fixed so that they will stay in place. Fig. 8 (*a*) and (*b*) shows two methods of bringing out side outlets by using special outlet fittings. In (*a*) the outlet tubes are fastened to the studding, in (*b*) the block is fastened to the lath. In bringing out wires through either the walls or

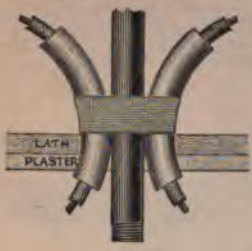
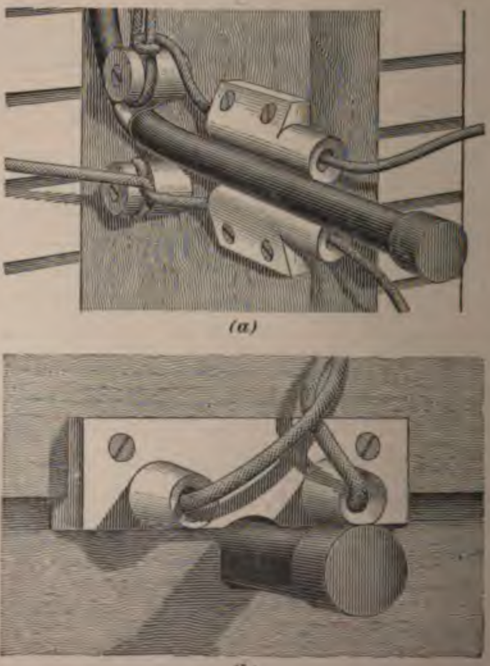


FIG. 7.



(b)

FIG. 8.

ceilings, see that there is no danger of their coming in contact with gas pipes or plaster.

23. For running wires parallel to joists, knobs are generally used because they make it possible to keep the wires well separated. The following rules apply to this kind of work:

Wires—

For concealed "knob-and-tube" work:

a. Must have an *approved* rubber-insulating covering.

b. Must be rigidly supported on non-combustible, non-absorptive insulators that separate the wire at least 1 inch from the surface wired over, and must be kept at least 10 inches apart, and, when possible, should be run singly on separate timbers or studding.

c. Must be separated from contact with the walls, floor timbers, and partitions through which they may pass by non-combustible, non-absorptive insulating tubes, such as glass or porcelain.

Rigid supporting requires under ordinary conditions, where wiring along flat surfaces, supports at least every 4½ feet. If the wires are liable to be disturbed, the distance between supports should be shortened.

When, from the nature of the case, it is impossible to place concealed wiring on non-combustible, insulating supports of glass or porcelain, an *approved* armored cable, single or twin conductors, may be used if it is installed without joints between outlets, and the cable armor properly enters all fittings and is rigidly secured in place; or, if the wires are not exposed to moisture, they may be fished on the loop system if separately encased throughout in approved flexible tubing or conduits.

d. Conduit, even when used in connection with concealed knob, tube, and conduit work, must be continuous from outlet to outlet, and comply with rules covering interior conduits.

e. Must at outlets for combination fixtures (i. e., fixtures for both gas and electric light) be bushed with flexible insulating tubes extending in continuous lengths from the last porcelain support to

1 inch beyond the outlet, except that an approved outlet insulator may be used. At outlets where there are no gas pipes, either this class of construction or porcelain tubes may be used.

An armored cable will rarely be required in connection with concealed knob-and-tube work in a new building, where everything is accessible; but in an old building, where there are objections to tearing up floors to insert wires, it may be used to considerable advantage. Fig. 9 shows such an armored twin conductor suitable for this purpose, which means that it complies with the following specifications:

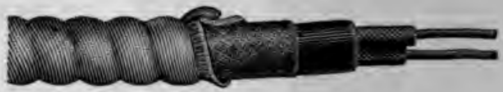


FIG. 9.

Armored Cable.—

a. The armor of such cables must be at least equal in thickness and of equal strength to resist penetration by nails, etc. as the armor of metal coverings of metal conduits.

b. The conductors in same, single wire or twin conductors, must have a rubber-insulating covering; any filler used to secure a round exterior must be impregnated with a moisture repellent, and the whole bunch of conductors and fillers must have a separate exterior covering.

Such cables may be used to wire buildings without any porcelain tubes whatever, as the insulation required is very high; but the system requires special fittings and tools for installing it and has not yet come into very extensive use, probably on account of its expense.

24. The protected flexible cord, of the same style, is a very convenient article to use in wiring offices, banks, etc., where small conductors must be carried behind desks or fastened to iron or cabinetwork, and in many other places where ordinary cords will not do and will not be permitted.

25. The calculations for concealed wiring are the same as for open work; but it must be remembered that rubber-covered wires are not to be allowed to carry as much current as weather-proof wires, as shown by the Underwriters' Table of Carrying Capacities.

26. Use of Cabinets and Panel Boards.—For concealed work, the **closet,** or **cabinet,** system of distribution is now universally used. In this method of wiring, the mains are run to *cabinets* or *panel boards* set in the wall, and from these the lines running to the lamps are distributed. Many different styles of these panel boards are manufactured, and the style used will depend largely on the size and allowable cost of the installation. For the cheaper class of work, the cut-outs may be grouped together and placed in a cabinet formed in the wall. This cabinet should be neatly lined with ⅛-inch asbestos; and where the wires pass into and out of the sides or bottom, they should be bushed with porcelain tubes. A neat glass or asbestos-lined door should be provided. A cabinet made in this way is inexpensive and safe and meets the requirements of the Underwriters. In more expensive installations, the panel boards are made of slate or marble and the sides and bottoms of the boxes are also of slate or marble.

Fig. 10 will give an idea as to the essential parts of a panel board. In this case the two wires are run in a conduit. The box is mounted in the wall and consists of two compartments, the inner compartment

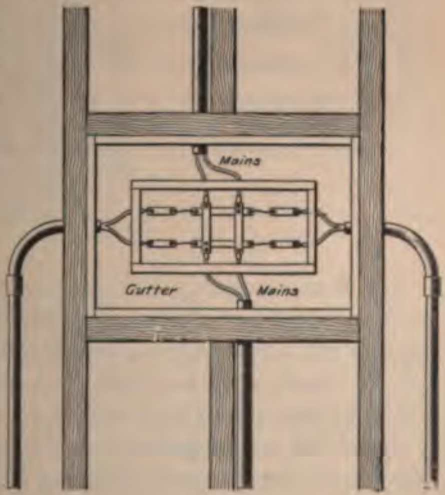


FIG. 10.

containing the panel board, and the outer one, or *gutter*, as it is sometimes called. All boxes are not provided with this gutter, but the best ones are, as it gives a convenient space in which to arrange the wires in case they should not come to the box in the best order for connecting up. The box is made of slate or marble slabs. The trim around the door covers the gutter; it should be put up with screws so that it may be removed if necessary.

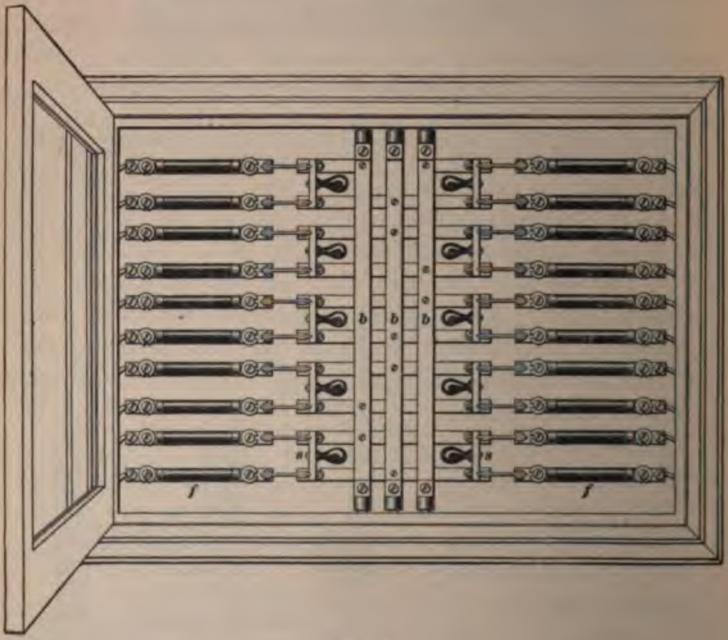


FIG. 11.

The mains usually pass through the panels vertically and are connected to bars from which the various lamp circuits branch out sidewise. Fuses are inserted in each side of each circuit, and switches are in some cases also provided; though frequently the panel board carries fuses only.

Fig. 11 shows a panel board equipped with double-pole switches *s* and enclosed fuses *f*. Ten branch circuits are accommodated and the three-wire vertical mains are attached to the copper bars *b*, *b*, *b*; the mains enter at the bottom and pass out at the top to the floor above.

27. Instead of building a wooden box in the wall to take the slate or marble pieces that go to make up the cabinet, iron or steel boxes are now used in much of the better class of work. Fig. 12 shows a cabinet of this kind ready to be set into the wall and connected up. It is made of a sheet-steel box *a*, whose sides and top are lined inside with ¼-inch slate slabs *b*. The panel board *c* constitutes the back of the box. In the figure the openings *d* for the branch circuits are arranged to take conduits, but the same style of box can be provided with porcelain bushings for wiring done on porcelain. If it is necessary to have a distributing space, or gutter, around the cabinet, it is covered

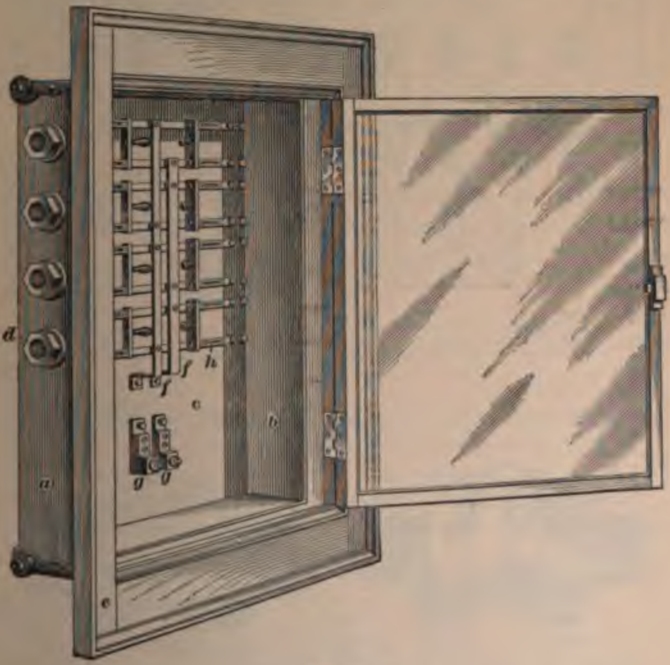
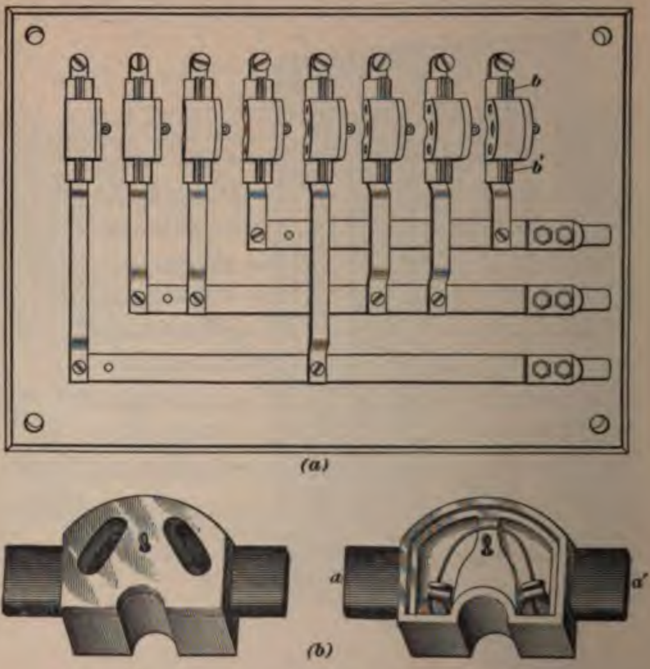


FIG. 12.

by the trim *e* projecting around the box. The two-wire vertical mains are connected to terminals *g*, *g* and, through the main fuses, to the bars *f*, *f*. Each branch circuit is provided with fuse terminals and a knife switch *h*.

Fig. 13 (*a*) shows a style of panel board that uses a special kind of fuse holder that serves the purpose of a switch when it is desired to disconnect any circuit. Panel boards using combination fuse holders have been adopted quite largely, for they have one advantage in that the holder may be entirely removed from the board when the fuse is being replaced, or another reserve holder may be put in instead of the one removed. Fig. 13 (*b*) shows one of these holders. It is held in place by the clips *b*, *b'* that receive the blades *a*, *a'*. Fig. 14 shows a plain two-wire board for four branch circuits; it is equipped with Edison fuse plugs and



(*a*)

(*b*)

FIG. 13.

has no switches. The above will give a general idea as to the construction of these boards. They are made in all sorts of combinations and, in fact, are usually made to order for any given job. In large wiring systems, the design of the cut-out closets, or cabinets, is a matter of great importance, and the location of these closets is equally important; they should be placed in a position where they can be readily reached.

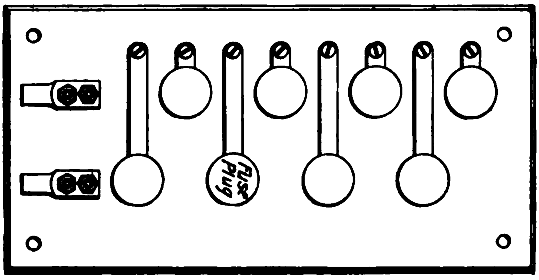


FIG. 14.

28. The following Underwriters' rules relate to cut-out cabinets:

Cut-Out Cabinets—

> Must be so constructed and cut-outs so arranged as to obviate any danger of the melted fuse metal coming in contact with any substance that might be ignited thereby.

The following specifications should be followed:

Material.—

> *a.* Boxes may be of marble, slate, or wood. If wood is used, the inside of the box must be lined with non-combustible material, such as slate or asbestos board. If asbestos board is used, it must be at least $\frac{1}{8}$ inch in thickness, must be neatly put on, and firmly secured in place by shellac and tacks.

Door.—

> *b.* The door must close against a rabbet, so as to be perfectly dust-tight. Strong hinges and a strong hook or catch are required. Glass doors

must be glazed with heavy plate glass, not less than $\frac{3}{16}$ inch in thickness and panes not to exceed 1 foot in width. A space of several inches should be allowed between the fuses and the door, especially when glass is used. This is necessary to prevent cracking or breaking by the severe blow and intense heat that may be produced under some conditions.

Bushings.—

c. Bushings through which wires enter must tightly fit the holes in the box and must be of approved construction.

Wires should tightly fit the bushings, tape being used to build up the wire, if necessary, so as to keep out the dust.

WIRING A DWELLING HOUSE.

29. In laying out the wiring for a dwelling house, the first thing to do is to select a place to locate the cut-out cabinets. In many dwelling houses, only one cut-out cabinet may be necessary, but in houses designed to be occupied by more than one tenant, a cut-out cabinet should be installed for each tenant. In large houses, it is often convenient to have a cut-out cabinet on each floor, with vertical mains running through them from the top to the bottom of the house. If only one distributing point is used, it should be either in the cellar or attic and risers run to the different floors. If it is known that the wires are to enter the building in the cellar, then the distributing center should be located there; if the wires enter in the attic, the distributing point should be located there. This assumes that vertical risers are run from the distributing center to feed the various floors. In case a single pair of vertical mains is used with the circuits branching off on each floor, the mains may be run from the top to the bottom of the house and the current supplied from either end.

30. No matter what arrangement is adopted for distributing the current, the distributing centers, or cut-out cabinets, should be in or near a partition that is located so as to make the running of risers easy. They should also be as near the center of the building as possible and on an inside wall, so as to guard against dampness.

31. Figs. 15 and 16 show two floors of a typical dwelling. The distributing points are located in the hallway near the center of the house. It is usually advisable to locate the cut-outs in a hallway, if possible, because such location is generally central and easy to get at. The various branch circuits on the plans are indicated by single lines, although each line represents two wires. The wiring is supposed to be done on the ordinary concealed knob-and-tube system. The circuits are arranged so that there will be not more than 10 lights on any one circuit. Switches are placed on the side walls as shown at *s*. The switch for controlling the hall lights should be placed at some convenient point near the door, so that the lights may be turned on when entering the building. It is sometimes convenient to have another switch at the head of the stairs for controlling the hall light, so that the light may be turned on or off from either above or below. This requires the use of three-point switches, and the connections necessary will be explained later. In the plans, double-pole switches are indicated. Single-pole switches may, however, be used when not over 660 watts are controlled. They are cheaper to install than the double-pole switches.

32. Laying Out Circuits.—In laying out the various branch circuits, the first thing to do is to locate the lights on the plan and then group these lights for the different circuits, so that there will not be more than 10 or 12 lights on each one. After this is done, the lines may be marked; in doing this, due regard should be given to the direction in which the joists run, so that the wire may be put in with as little boring and cutting as possible. Run parallel to the beams wherever it can be done, even if it does take a little more wire. The best time to wire the building is after the floorbeams and studding are in place, but before any lathing or plastering has been done. In Fig. 15, four circuits are provided, all terminating in the cut-out cabinet in the hall, where they are attached to the vertical mains. For

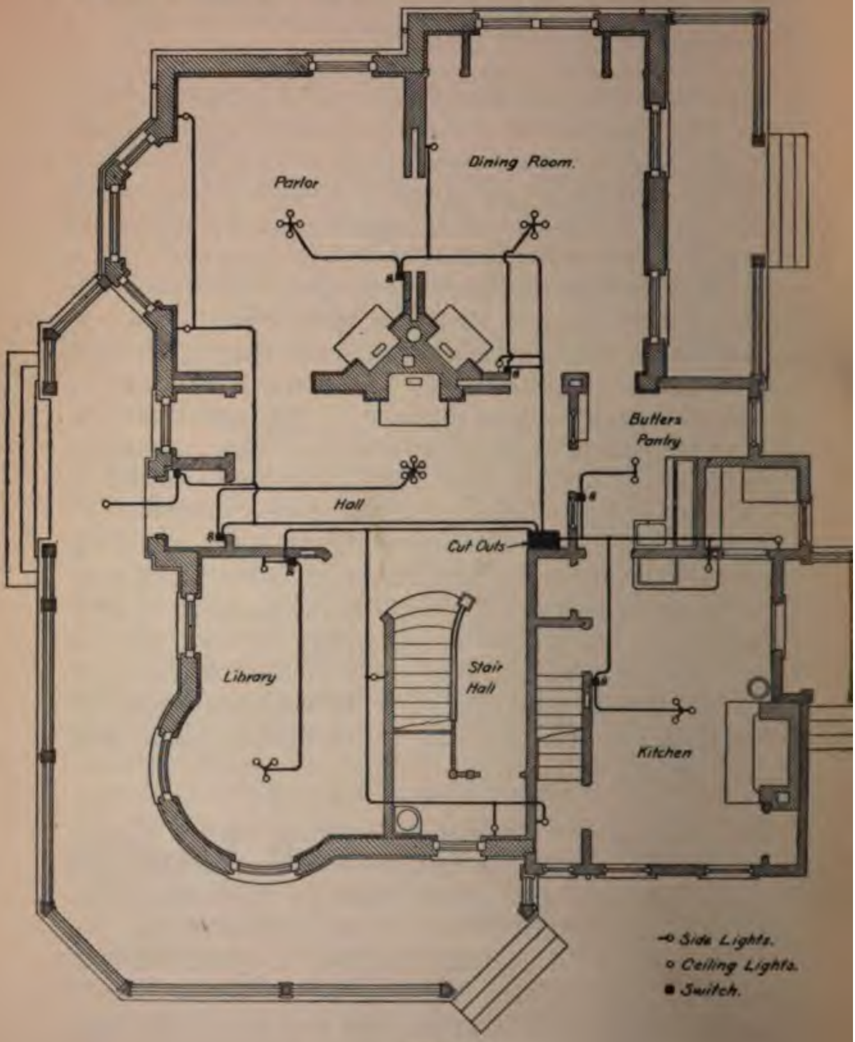


Fig. 15.

the second floor, Fig. 16, three circuits are sufficient. No. 14 wire is used for all these circuits. It will be found that No. 14 wire (the smallest that the Underwriters allow) is large enough for any of the branch circuits met with in

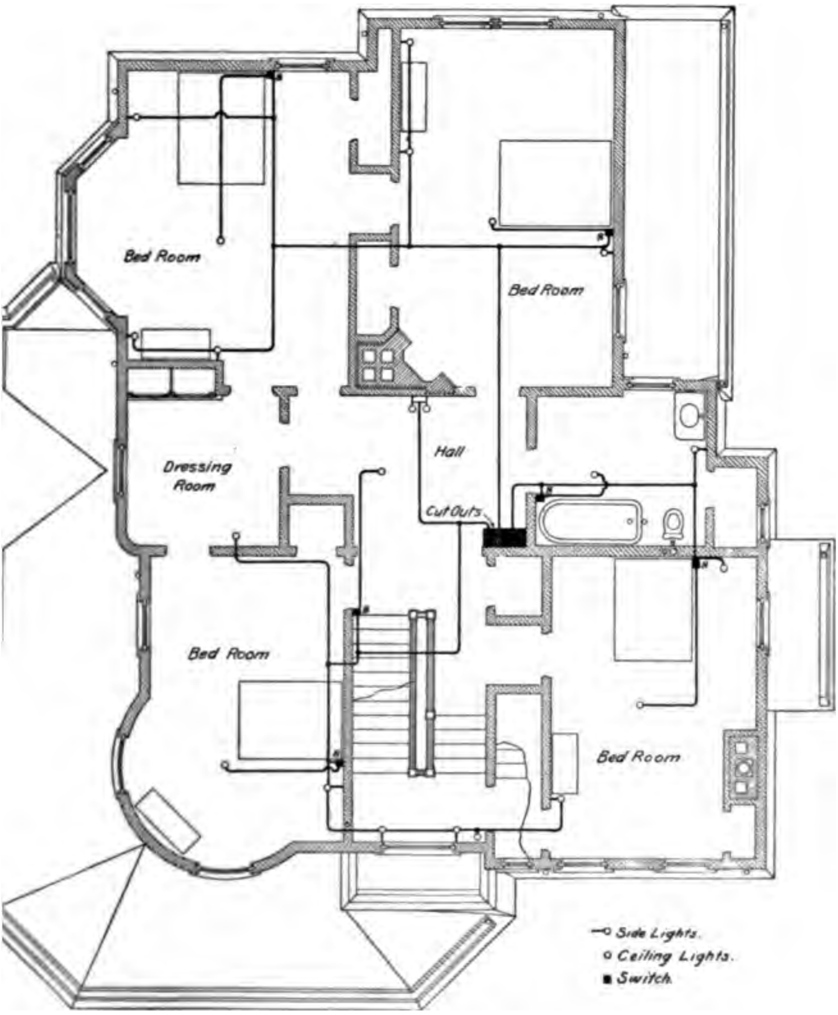


FIG. 16.

ordinary house-wiring work. The number of lights per circuit is small and the distances short, so that No. 14 will carry the current with but a small drop in voltage. This assumes that from 100 to 110 volts pressure is to be used. If 52 volts is the pressure of the supply, it is best to figure out the drop for each circuit. In most cases, it will be found advisable to use No. 12 wire. On new work 52 volts is seldom used, and in fact in work already installed, electric-light companies are changing the lamps over to 104 or 110 volts. In nearly all cases, therefore, No. 14 wire (rubber-covered for this kind of work) is sufficiently large for the branch circuits.

33. The Mains.—If vertical mains are used, the current that they will carry will be less at one end than at the other, because current is taken off at the different floors. It is usually advisable, however, to make the mains the same size all through an ordinary house, because it costs but little more and enables the current to be supplied from either end. Of course, in large buildings it would not pay to do this. In large buildings it is customary to have a number of risers feeding different sections of the building, all of which run to a common distributing point, usually located in the basement. The mains must, of course, be designed to carry the current in accordance with the Underwriters' requirements or to limit the drop to the allowable amount if the wire required by the Underwriters will give too much drop. In the house under consideration, suppose we have a total of 60 lamps. The current in the mains will then be 30 amperes, and we will need at least a No. 8 wire to satisfy the Underwriters' requirements.

By referring to Table II, it is found that No. 8 wire will carry 30 amperes a distance of 25.5 feet with a drop of 1 volt. For a building of this kind, the drop from the point where the current enters the building to the lamps should not exceed 2 to 2.5 volts. The drop in the branch circuits will be very small, but it would be advisable to put in No. 6

mains, as the difference in first cost will be but little. It is the usual practice to make the mains of liberal cross-section. For a house of this size No. 4 would often be used, although it does not need to be as large as this so far as drop is concerned.

34. Main Switch, Cut-Out, and Meter.—At a convenient point near the place that the wires enter the building, a main cut-out and switch must be placed, as required by the Underwriters. The cut-out should be placed nearest the point of entry, the switch next to it, and the meter last. Never permit the meter to be installed between the switch and the cut-out, as in that case it may register a small amount each day, even if the switch be open. It is best to use a knife-blade switch at the entrance to the building, and this switch should be so placed that when opened it will not tend to fall closed of its own accord.

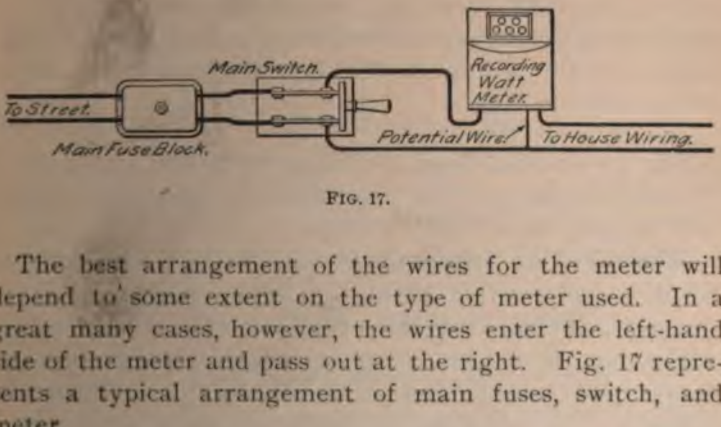


FIG. 17.

The best arrangement of the wires for the meter will depend to some extent on the type of meter used. In a great many cases, however, the wires enter the left-hand side of the meter and pass out at the right. Fig. 17 represents a typical arrangement of main fuses, switch, and meter.

Most recording electric meters consist of a small electric motor, the revolving part of which turns on jeweled bearings and is connected to a train of gears and dials. The motor is governed by means of retarding devices, so that it runs at a speed accurately proportional to the load. Some meters read in ampere-hours, others in watt-hours.

Most of those now installed read in watt-hours and are provided with two coils, one of which is connected in series with the circuit, like an ammeter, and the other across the circuit, like a voltmeter. The current in the first is, therefore, equal to the current supplied, and the current in the second is proportional to the voltage. The force tending to drive the motor is proportional to the product of the two, i. e., to the watts. The small third wire running into the meter, Fig. 17, is to supply current to the potential coil. With ampere-hour meters, a series coil only is used, and the speed of the meter is proportional to the current and not to the watts.

The voltage of a lighting system is, however, practically constant, so that the watt-hours may be obtained by multiplying the ampere-hours by the voltage without serious error. Reliable meters are made for all voltages and systems and for alternating or direct currents. They are accurate to within 98 per cent. on ordinary loads, but are liable to be out as much as 5 per cent. on small loads, and most meters will take a certain very small load without turning at all. However, they are seldom operated under such conditions.

35. In new buildings, it is often not known what system of electric lighting will be used when the wiring is finished. Owners also desire quite frequently to be able to avail themselves of any advantage in price that may be brought about by competition between different systems. It is, therefore, desirable that each new house shall be wired in such a manner that light may be secured from any system in use—that is, from 52-, 110-, or 220-volt two- or three-wire systems. The following typical specifications cover all the main points necessary for such a piece of work in an ordinary dwelling house.

Other details, such as the location of additional switches, the use of particular kinds of cut-outs, etc., may be added to these specifications if desired. The specifications cover only the concealed work.

Specifications for Concealed Electric-Light Wiring.

For 52-, 110-, or 220-volt systems.

Distribution Closet.

A distribution closet is to be located on some inside wall, in a readily accessible place, on the second floor or the attic, as near the center of the building as possible.

The closet must be lined with asbestos ⅛ inch thick and fitted with a door covered on the inside with asbestos ⅛ inch thick.

Circuits.

From this closet separate circuits must be run to the outlets in such a manner that not more than eight 16-candlepower incandescent lamps shall be placed on any circuit. Wherever the number of lamps is not marked on the plans or otherwise specified as greater than here required, pendants shall be considered as intended to carry four lamps each and brackets one lamp each.

Fuse Blocks.

All fuse blocks must be placed in the distribution closet. They must be made of porcelain, must have a breaking distance of 1½ inches, and must be capable of standing the arc caused by the breaking of a 10-ampere fuse on a 220-volt short circuit without cracking the porcelain. Both sides of all lines must be fused.

Wires.

All circuits running from the distribution center must be of No. 14 B. & S., or larger, rubber-covered copper wire of a make accepted by the National Board of Fire Underwriters.

Mains.

From the distribution closet to the attic, and also to the basement, a pair of mains must be run, the size of which will depend on the total number of lights in the house, as follows:

17 lamps, or less,	No. 12 or larger.
18 to 24 lamps, or less,	No. 10 or larger.
25 to 33 lamps, or less,	No. 8 or larger.
34 to 46 lamps, or less,	No. 6 or larger.
47 to 65 lamps, or less,	No. 4 or larger.

If the house contains more than 65 lamps, it is advisable to have more than one distribution center and pair of mains.

Extra Wire. A third wire, two sizes smaller than these mains, must also be run from the attic to the basement, through the distribution closet, to make possible the use of the three-wire system.

Manner of Fastening Wires. Wires running parallel to joists must be fastened on porcelain knobs, placed on different timbers, and kept as far apart as possible. In passing through joists, floors, and other woodwork, the holes must be bushed with porcelain tubes, which must extend at least ½ inch through the wood and be so arranged that their weight will tend to keep them in place rather than to cause them to slip out.

Space Between Wires. All wires must be kept at least 2½ inches away from one another, from gas or water pipes, iron beams, bell, or annunciator wires, speaking tubes, furnace pipes, and other conducting materials, except at the distribution closet and fixture outlets. Where a wire must cross any such conducting wire, pipe, or material with less clearance, it must have its insulation reenforced by a porcelain tube.

Outlets. Porcelain tubes (or outlet blocks) must be used at outlets. Special care must be taken to insulate from the gas pipe at outlets.

Running Along Brick or Stone Walls. Brick and stone walls must be avoided wherever possible. Wherever wires pass along them, they must be encased in approved conduit.

Main-Line Cut-out and Fuse.

There must be supplied and installed by the contractor a main-line cut-out and a quick-break switch, both double pole, to be located in the attic at the end of the feeder lines. These devices must be approved by the Underwriters as capable of breaking the current for the total number of lamps wired, at either 52 or 220 volts. Knife switches, if used, must be so connected that they open downwards and the blades must be "dead" when the switch is open.

Inspection, Certificate, and Payment.

The contractor must notify the Underwriters' Association of the progress of his work in time to have a thorough inspection made (two days before work is concealed at least). He must secure a certificate from that Association stating that the work is suitable for use on 52-, 110-, or 220-volt service, two- or three-wire systems, before any payments shall be made to him.

SWITCHES.

36. Switches located at various points on the walls of rooms are a great convenience and should be installed on all first-class jobs of any magnitude. The single-pole snap switch (for not more than 660 watts) is the simplest and cheapest. It opens one side of the circuit only. Next in frequency of its use is the double-pole snap switch for larger chandeliers or groups of lights. In addition to these, there are a number of special uses of switches to allow lamps to be controlled from two or more points.

37. Control of Lamps From Two Points.—Fig. 18 (*a*) and (*b*) shows a switching arrangement for controlling the light or group of lights *L* from two points *A* and *B*. This scheme is used principally in halls where it is desired to control the light from either up or down stairs. It requires two three-point switches *S*, *S'*, which are here shown as simple lever switches. There are a number of different makes of switches for this purpose, but the principle of all is the same, though the mechanical details may differ. By comparing the diagrams with whatever make of switch he may have to install, the student should have no difficulty in getting the connections correct. By examining the connections, the student will readily see that the lamps *L* may be lighted or extinguished from either point. Either method

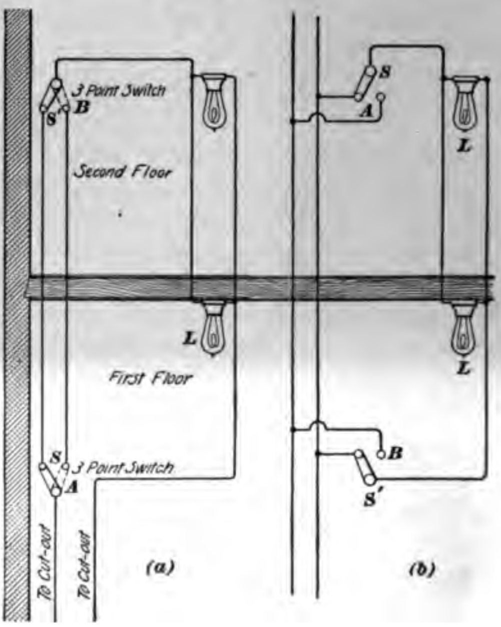


FIG. 18.

of connection (*a*) or (*b*) may be used, and the one that will be most convenient in any given case will depend to some extent on the general layout of the wiring.

A modification of this arrangement is shown in Fig. 19 (*a*) and (*b*). In this case, one of the three-way switches is replaced by a three-way socket. By using a three-way socket on the fixture in connection with a three-way switch on the side wall, a lamp may be turned on or off either at the socket or at the switch. Both schemes of connection (*a*) and (*b*) accomplish the same result, and the one that is most convenient in any case will depend considerably on the location of the supply mains.

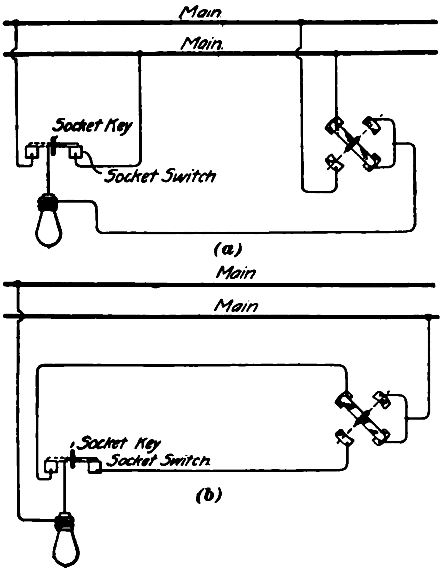


FIG. 19.

38. Control of Lights From Three or More Points.—Lights may be controlled from three stations, as indicated in Fig. 20. It is necessary to use two three-point switches *A*, *C* for the end stations and a four-point switch *B* for the middle station. When *B* is in the position shown, points *1* and *2* are connected together and *3* and *4* are also connected together. When the switch is turned, the former connections are broken and points *1* and *3*, *2* and *4* are connected. By tracing out the

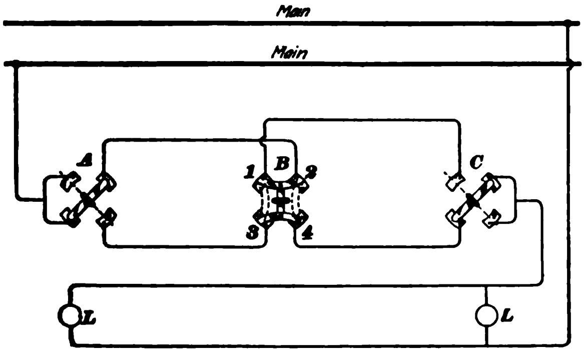


FIG. 20.

path of the current, the student will see that the lights may be turned on and off from any station independently of the position of the switches at the other stations. By cutting in another four-point switch for each additional station in the same way as B, this scheme can be extended to any number of stations desired, and is often used for stairways in flat houses.

39. Electrolier Switches.—These switches usually have three or four points and are used in connection with electroliers to enable a part or the whole of the lights to be operated as desired. Sometimes they are mounted in the electrolier itself. They are made in a variety of forms and the connections necessary are, as a rule, easily understood by an examination of the switch that it is proposed to use.

40. Snap Switches.—Ordinary snap switches are generally of a style similar to that shown in Fig. 21. They are mounted on porcelain bases and the working parts are covered by a metal cap. A switch of this kind is comparatively inexpensive, but it projects from the wall and does not make as neat a job as a switch arranged so that the working parts set into the wall. Moreover, they are always more or less liable to damage and take up space. The other type is known as a **flush switch.** Like snap switches, they are made in a large variety of styles and sizes.

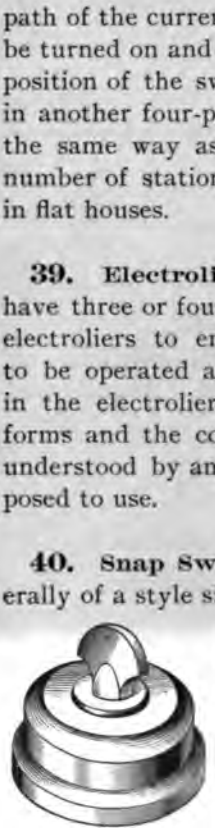


Fig. 21.

Fig. 22 gives an idea as to the arrangement of a flush switch. In this case the switch is operated by pushing the button projecting through the plate. The working parts are encased in porcelain and the face plate may be given any finish required to match the other hardware trimmings in the building. One of the terminals is shown at s. When one button is pushed in, lever l makes contact with c, c', thus completing the circuit. Snap switches, Fig. 23, are also made so that they may be mounted flush with the wall. When switches are mounted flush, an iron box should be provided in which to place them. Fig. 24 shows a switch box or frame of the kind referred to. A piece of board having an opening large enough to receive the box is nailed between the studding. The box is so mounted that the edge *a* will come flush with the plaster. The box is fastened in position by screws at *b*, *b* and the switch is fastened in the frame by screws *c*, *c*. The use of these frames makes a substantial job and the switch is held securely in place. The switches themselves are not usually installed in the boxes until the fixtures are put up.

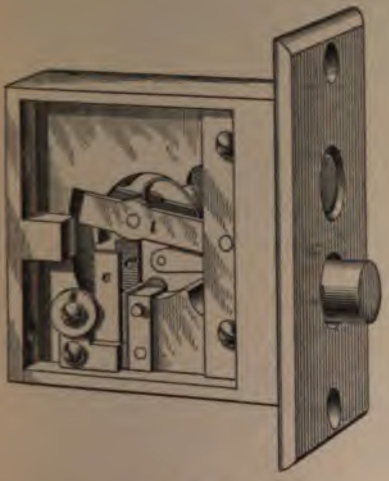


FIG. 22.

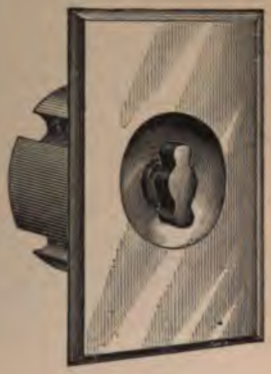


FIG. 23.

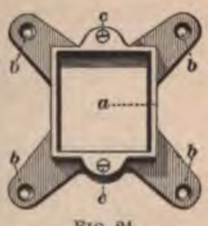


FIG. 24.

In selecting switches, it pays to get good ones. A great deal of trouble is caused by cheap, flimsy switches, in which the springs are always breaking or the parts working loose. A little extra investment put into good switches when the wiring is installed will save a great deal of annoyance and expense afterwards.

FIXTURES.

41. The selection of suitable fixtures and the proper wiring of them are important matters. The wireman should not be satisfied to put up any fixtures that may be furnished. He should examine them and test them himself. The following rules should be followed:

Fixtures—

a. Must, when supported from the gas pipes or any grounded metal work of a building, be insulated from such piping or metal work by means of *approved* insulating joints placed as closely as possible to the ceiling.

It is recommended that the gas outlet pipe be protected above the insulating joint by a non-combustible, non-absorptive insulating tube having a flange at the lower end where it comes in contact with the insulating joint; and that where outlet tubes are used, they be of sufficient length to extend below the insulating joint and that they be so secured that they will not be pushed back when the canopy is put in place. Where iron ceilings are used, care must be taken to see that the canopy is thoroughly and permanently insulated from the ceiling.

b. Must have all burrs, or fins, removed before the conductors are drawn into the fixture.

c. The tendency to condensation within the pipes should be guarded against by sealing the upper end of the fixture.

d. No combination fixture in which the conductors are concealed in a space less than ¼ inch between the inside pipe and the outside casing will be approved.

e. Must be tested for contacts between conductors and fixture, for short circuits, and for ground connections before they are connected to their supply conductors.

f. Ceiling blocks for fixtures should be made of insulating material; if not, the wires in passing through the plate must be surrounded with non-combustible, non-absorptive insulating material, such as glass or porcelain.

42. Great care should be taken to see that the sockets are good, and also that they are strong enough to bear the weight of shades. Faulty sockets are more likely to cause trouble on fixtures than on drop cords, for the socket itself is always grounded on the fixture, and if either wire becomes grounded on the socket shell, it is in consequence grounded on the fixture.

INSULATING JOINTS.

43. The **insulating joint** is the most important electrical fitting used in fixture work. Joints are made for all possible combinations. Fig. 25 shows a very good style; piece *a* screws on to the gas pipe and *b* to the fixture. The parts are separated by insulating material *c*, and the outside of the joint is covered with molded insulation *d*. In connecting fixtures to the wiring, all wires should be kept away from the gas pipe above the joint, but they may be bunched in below the insulating joint after the wires have been spliced, soldered, and taped. It is very important to protect the gas pipe at this point. Insulating joints should be tested before being used. Canopy insulators should be installed wherever there are metal ceilings against which the canopies of fixtures might come. The **canopy** is the brass cup-shaped piece used at the top of fixtures to cover the joint. It is in contact with the fixture; hence, it is important that it be insulated from metal ceilings, or else all the benefits derived from an insulating joint will be lost. Fig. 26 shows a canopy insulator. It is simply an insulating ring placed between the canopy and the ceiling.

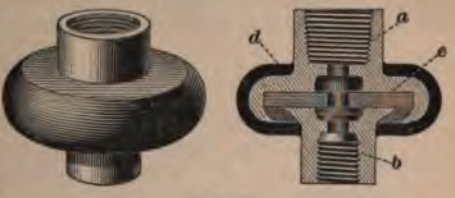


FIG. 25.

FIG. 26.

44. The student should note the following additional rules relating to insulating joints, fixture wire, etc.

Insulating Joints—

a. Must be made entirely of material that will resist the action of illuminating gases and will not give way or soften under the heat of an ordinary gas flame or leak under a moderate pressure. They shall be so arranged that a deposit of moisture will not destroy the insulating effect and shall have an insulating resistance of at least 250,000 ohms between the gas-pipe attachments, and be sufficiently strong to resist the strain they will be liable to be subjected to in being installed.

b. Insulating joints having soft rubber in their construction will not be approved.

Fixture Wire—

a. Must have a solid rubber insulation, with a slow-burning, tough, outer covering, the whole to be $\frac{1}{32}$ inch in thickness, and show an insulation resistance between conductors and between either conductor and the ground of at least 1 megohm per mile after 1 week's submersion in water at 70° F. and after 3 minutes' electrification with 550 volts.

b. Must not be less in size than No. 18 B. & S.

c. Supply conductors, and especially the splices to fixture wires, must be kept clear of the grounded part of gas pipes, and where shells are used, the latter must be constructed in a manner affording sufficient area to allow this requirement.

d. Must, when fixtures are wired outside, be so secured as not to be cut or abraded by the pressure of the fastenings or motion of the fixture.

e. Under no circumstances shall there be a difference of potential of more than 300 volts between wires contained in or attached to the same fixture.

Decorative Series Lamps.—

Incandescent lamps run in series shall not be used for decorative purposes inside of buildings except by special permission in writing from the Inspection Department having jurisdiction.

45. When old fixtures are to be wired, they must be taken down and supplied with insulating joints. Sockets may be attached to such old gas fixtures by means of spars that fasten to the fixtures at the gas burners. Fig. 27 shows three different styles of these spars.

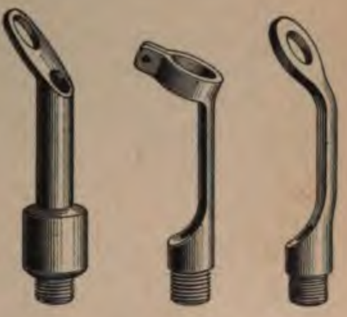


FIG. 27.

LOCATION AND DISTRIBUTION OF LAMPS.

46. The character of the lamps to be used and their location is a matter of much importance that must be determined in each case by the purpose for which the lamps are installed. For signs and decorative work, this purpose is solely to attract attention or to produce ornamentation. In interior lighting, it is to illuminate other objects either close at hand, as with desk lamps, or at a somewhat greater distance. Where illumination is the sole requirement, the lamps should preferably be placed where they cannot be seen, but where they will throw their light upon the object to be illuminated, as on the stage of a theater. In general work, however, it is not possible to place the lamps in this manner, but they should be placed where they will not be too conspicuous. When they must be in view, the lamps should be surrounded by shades that will diffuse the light and take away the glare. Frosted globes are of assistance in many places, but it is better to have the light diffused by a shade. Shadows should be avoided as much as possible.

47. Chandeliers are usually relied on for general illumination. They should be hung high to get the best effects, and should never be as low as the level of the eye of a person standing. Borders or rows of lights placed on the ceiling near the walls give very good illumination without hurting the eyes. To get the best illumination with the smallest number of lamps, the walls and ceilings should be finished in light colors or in white and kept clean. It is cheaper to retint ceilings than to burn many lamps. This is especially true of stores, where much illumination is a necessity. Walls papered in dark colors and woodwork of dark, rich wood make it almost impossible to brilliantly light a room.

48. It is an exceedingly difficult matter to give any rule for determining the number of lamps required to light a room of given size. Very much depends on the degree of illumination required, on the height at which the lamps are placed, and the color of the walls and ceilings. Experience is about the only reliable guide. The following number of lamps for 100 square feet (Table V) will give an approximate idea as to the number of lights required to produce a given effect, but these values must not be considered as fixed by any means:

TABLE V.

Number of 16-Candlepower Lamps per 100 Square Feet.	Illuminating Effect.
1.25	Dull
1.75	Medium
2.25	Good
3.00	Bright
4.00	Brilliant

If globes are used, the above effects will be reduced.

CONDUIT WIRING.

EARLY CONDUIT SYSTEMS.

49. Not many years ago, before there were uniform rules governing the installation of wires to make them safe, it was a common practice to use for electric lighting wires wound with cotton thread saturated with paraffin. These wires were fastened with wooden cleats nailed against the walls and ceilings. Signal and bell wires are still sometimes put up in this way. The first step in the direction of improvement was limiting the number of incandescent lamps allowed on a given size of wire. The next was the substitution of "weather-proof" or "Underwriters'" wire for the paraffin-covered "office wire." Later came the porcelain cleat, which was not in general use before 1892.

50. The manner of installing wire in concealed work has undergone a similar evolution. At first wires were pulled through holes in the joists and installed without any protection other than their insulating covering; sometimes even two wires were pulled through the same hole, but this was not long tolerated. Progress came along two distinctly different lines: one that of insulating the wire by the use of knobs and tubes, as previously described; the other that of providing a continuous raceway, or **conduit,** for the conductors.

51. One of the first conduit systems and one that came into very extensive use, though it is not now allowed by the Underwriters, was that of the Interior Conduit and Insulating Company. This conduit was made of paper wound in an ingenious manner, so as to form a tube, and coated with tar inside and out. These tubes were installed as a continuous raceway from outlet to outlet. One or two wires, as happened to be most convenient, were pulled into each conduit.

paper tubes were very brittle, and the system was ed by covering them with a thin shell of sheet brass. ne the requirement that the conduit should never ore than one wire. At one time, "brass-covered, or conduit work" was considered the best possible kind nstruction.

These paper conduits may still be used to advantage pecial places, especially in running wires up and down k walks, in connection with knob-and-tube work, as an ditional protection to wire ased in plaster. It is quite as good as, and in some res better than, iron pipe for this purpose; and though th derwriters do not endorse most inspectors pass n thus used. It is also frequently used in place of m g, where wires are run on the surface of walls or in c s, where ordinary molding would be awkward. But it ot tolerated as a conduit proper, because it is not str enough. Nails can easily be driven through it.

53. Another excellent tub hat may still be used in some places, though not approved as a conduit proper, is the flexible **Circular-Loom** tube. This is a woven tube treated with insulating material that makes it hold its shape. It has no metal covering, but is stronger than the brass-covered, interior conduit and more convenient to use. It will be permitted under the present rules only in special cases, as it is not waterproof or nail-proof.

APPROVED CONDUIT SYSTEMS.

54. The conduits now approved by the Underwriters are all iron pipes with more or less insulating lining. They are divided into two classes, *lined* and *unlined*. When unlined conduits are used, an additional braided covering must be placed on the wire. Conduits must comply with the following specifications:

Specifications for Interior Conduits.—

a. Each length of conduit, whether insulated or uninsulated, must have the maker's name or initials stamped in the metal or attached thereto in a satisfactory manner, so that the inspectors can readily see the same.

Metal Conduits with Lining of Insulating Material:

b. The metal covering or pipe must be equal in strength to the ordinary commercial forms of gas pipe of the same size, and its thickness must be not less than that of standard gas pipe, as shown by the following table:

Size, Inches.	Thickness of Wall, Inches.	Size, Inches.	Thickness of Wall Inches.
½	.109	1¼	.140
⅝	.111	1½	.145
¾	.113	2	.154
1	.134		

An allowance of $\frac{2}{100}$ inch for variation in manufacturing and loss of thickness by cleaning will be permitted.

c. Must not be seriously affected externally by burning out a wire inside the tube when the iron pipe is connected to one side of the circuit.

d. Must have the insulating lining firmly secured to the pipe.

e. The insulating lining must not crack or break when a length of the conduit is uniformly bent at temperature of 212° F. to an angle of 90°, with a curve having a radius of 15 inches for pipes of 1 inch and less and 15 times the diameter of the pipe for larger pipes.

f. The insulating lining must not soften injuriously at a temperature below 212° F. and must leave water in which it is boiled practically neutral —that is, neither acid nor alkali.

g. The insulating lining must be at least $\frac{1}{32}$ inch in thickness and the materials of which it is composed must be of such a nature as will not have a deteriorating effect on the insulation of the conductor, and be sufficiently tough and tenacious to withstand the abrasion test of drawing long lengths of conductors in and out of same.

h. The insulating lining must not be mechanically weak after 3 days' submersion in water, and when removed from the pipe entire must not absorb more than 10 per cent. of its weight of water during 100 hours of submersion.

i. All elbows or bends must be so made that the conduit or lining of same will not be injured. The radius of the curve of the inner edge of any elbow not to be less than 3½ inches. Must have not more than the equivalent of 4 quarter-bends from outlet to outlet, the bends at the outlets not being counted.

Unlined Metal Conduits:

j. Plain iron or steel pipes of equal thickness and strengths specified for lined conduits may be used as conduits, provided their interior surfaces are smooth and free from burrs; pipe to be galvanized or the interior surfaces coated or enameled, to prevent oxidization, with some substance that will not soften, so as to become sticky and prevent wire from being withdrawn from the pipe.

k. All elbows or bends must be so made that the conduit will not be injured. The radius of the curve of the inner edge of any elbow not to be less than 3½ inches. Must have not more than the equivalent of 4 quarter-bends from outlet to outlet, the bends at the outlets not being counted.

55. Fig. 28 shows a piece of iron-armored, lined conduit; *a* is the armor about $\frac{1}{8}$ inch thick, which is the same as ordinary gas pipe; *b* is the insulating lining, not less than $\frac{1}{32}$ inch thick and adhering to the outer pipe. Conduit, whether lined or unlined, is put up in the same manner as a good job of gas-fitting. Great care should be taken at the joints to see that the pipe is reamed and that the ends come together, so as to form a smooth runway (free from burrs) for the wire. Fig. 29 shows an elbow. In many places the conduit itself may be bent and the use of an elbow with its threaded joints avoided. About as good a way as any to bend conduit is to get a good, stout piece of spruce or hard pine and bore a hole in it a little larger than the conduit. The pipe is then passed through

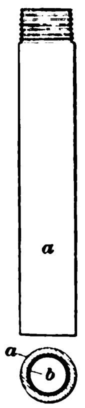


FIG. 28.

the hole and the bend may be easily worked in. For iron-conduit wiring, the wireman should be provided with a regular outfit of pipe fitter's tools.

56. As previously mentioned, most conduit wiring is now carried out on the single-tube system; i. e., both wires or a twin wire are run in the same conduit. This plan requires less conduit and labor than the double-tube system and is in fact the only allowable arrangement when alternating currents are used. In the case of a large church, supposedly wired for 52 volts, 2 per cent. loss, the contractor ran wires in separate pipes, with the result that when the current was turned on only 13 volts were obtained at the lamps. It is cheaper, as well as better, to use twin or concentric conductors in a single conduit, except for very large cables which are to carry continuous currents.

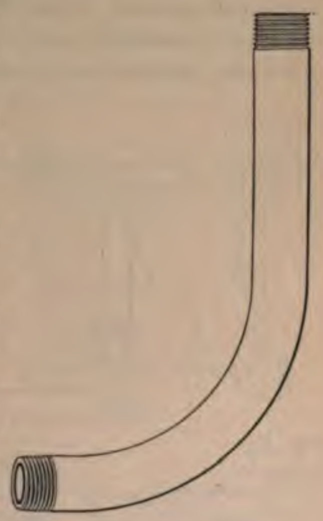


FIG. 29.

57. Use of Outlet and Junction Boxes.—Since in any conduit system the primary object is to have the wires arranged so that they may be withdrawn, it is necessary, whenever a branch is taken off, to provide a **junction box** of some kind, because it is evident that splices cannot be made at intervening points without interfering with the withdrawal of the wires. Conduit wiring is, therefore, done on the so-called **loop system.** This will be understood by referring to Fig. 30 (*a*) and (*b*); *L*, *L*, *L*, etc. are lamps on one circuit that is to be supplied from a panel board or distributing center located at *A*. In (*a*) the wiring is indicated as it might be done with the ordinary knob-and-tube system, using branches whenever they will reduce the labor and the amount of wire necessary; (*b*) shows the same lamps wired on the loop system, using outlet boxes *b* and looping out the twin wire at each lamp. No branches are taken off between outlet boxes, and by disconnecting the wires running to the lamps, the main wires may be withdrawn.

The loop system using iron conduits is, of course, very much more expensive than the knob-and-tube system. It is, however, much more permanent in character and is the only style now used in the best class of buildings. It is used altogether in modern fireproof buildings. The best method of running the conduit, so as to save bends and make the conduit as short as possible, must be left to the judgment of the wireman. In laying out such wiring, he must remember that the two wires are run together and that he cannot make short cuts with single wires as in knob-and-tube work.

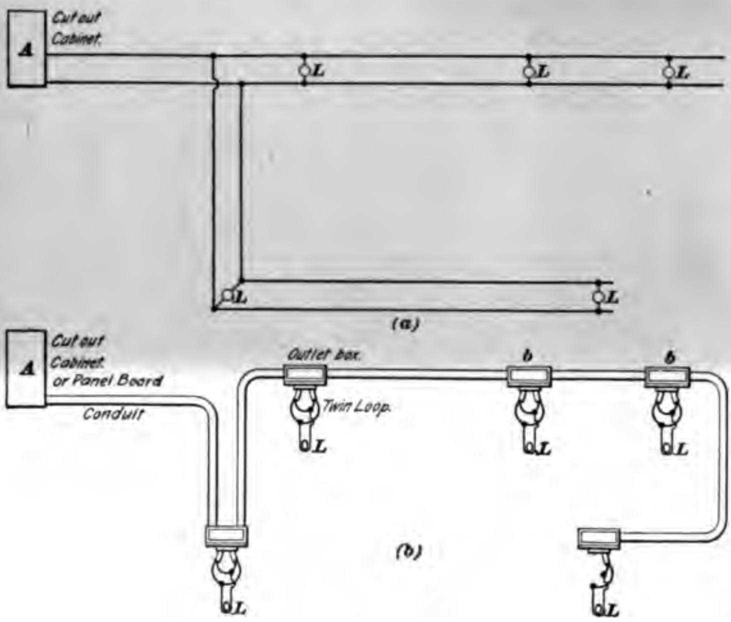


FIG. 30.

58. Conduits less than ⅝ inch inside diameter are not allowable and an outlet box should be provided at every outlet. When branch lines are taken off, a junction box must be provided. There should not be more than the equivalent of four right-angled bends between junction boxes or there will be difficulty in pulling through the wire. Junction boxes and outlet boxes are manufactured in a large variety of forms to accommodate conduits coming into them from different directions. Fig. 31 (*a*) shows a round junction box. These boxes should be mounted firmly in the wall and be placed so that the surface will come flush with the plastering. The split nuts *a*, *a* hold the conduit in place. Fig. 31 (*b*) shows an **outlet plate.** The conduit is clamped in openings *a* and the gas pipe is clamped in *b*. Very convenient junction and outlet boxes are now made of stamped steel and are arranged so that one or more openings may be made in the side by taking out a small disk. Fig. 32 shows a box of this kind. The conduit enters the box and, projecting through it about ½ inch, is held in place by an insulation cap *a* that screws over the end on the inner side. A check nut *b* screws up against the outside of the box. Fig. 33 shows these fittings more in detail. Boxes of this type may be suited to different locations by simply

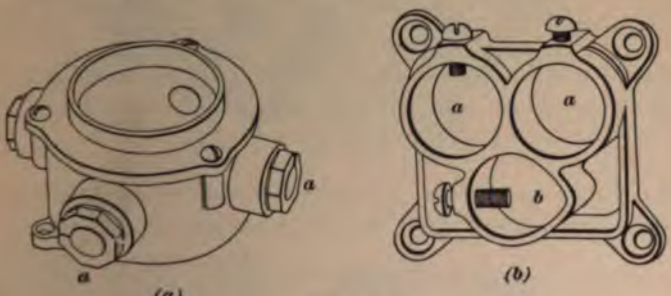


FIG. 31.

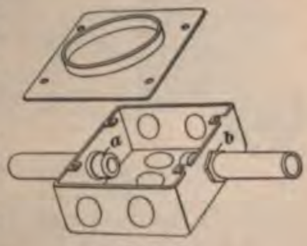


FIG. 32.

knocking out or removing the disks whenever openings are needed. This avoids the necessity of carrying a large number of different boxes in stock. Outlet boxes may be obtained that are provided with special covers to accommodate almost any make of flush switch.

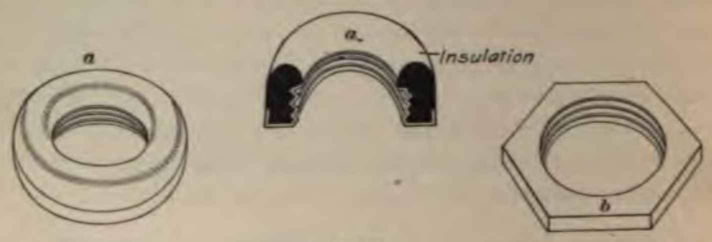


FIG. 33.

59. Fig. 34 shows a flush switch (with face plate removed) mounted in a switch box suitable for use with iron-armored conduit. Outlet boxes are also made for use with combination fixtures; they are provided with openings for the gas pipe to pass through.

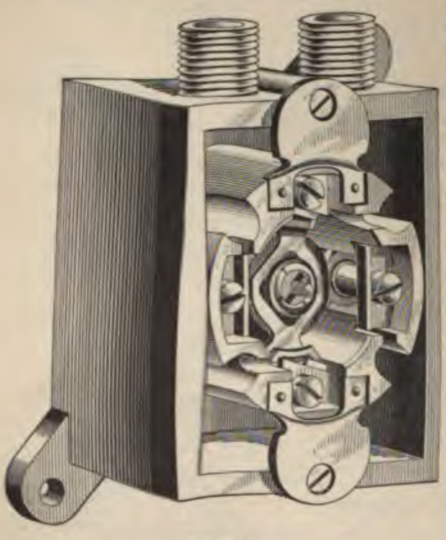


FIG. 34.

When a change in the size of wire is made in a junction box, it is necessary to protect the branch circuits by a cut-out. Special cut-outs are made suitable for mounting in junction boxes. Fig. 35 shows a cut-out suitable for a square box like that shown in Fig. 32. Outlet boxes and cut-outs are also made for places where both gas and electricity are used.

60. Fig. 36 (*a*) and (*b*) shows the method of mounting an outlet box in a fireproof ceiling. By crossing the ells as shown at (*b*), the fireproof brickwork does not need to be cut as much as when they are not crossed, as in (*a*). The face of the box should come flush with the plastering. Cement or plaster of Paris may be run in around the box and elbows to hold them securely in place. In work of this kind the conduit is usually run on the upper surface of the fireproof floor as indicated; the strips on which the wood floor is laid usually make sufficient space between the fireproof brick and the wood floor to accommodate the conduit. Where iron conduit is attached to wood beams, it is held by pipe straps in the same way as gas pipe.

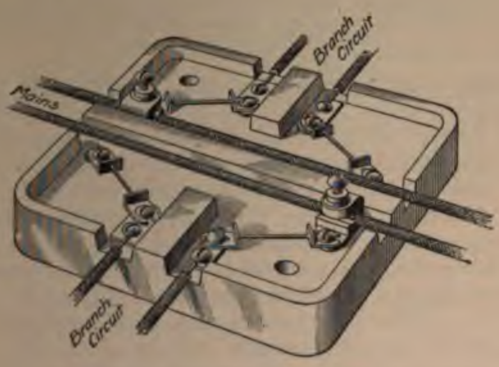


FIG. 35.

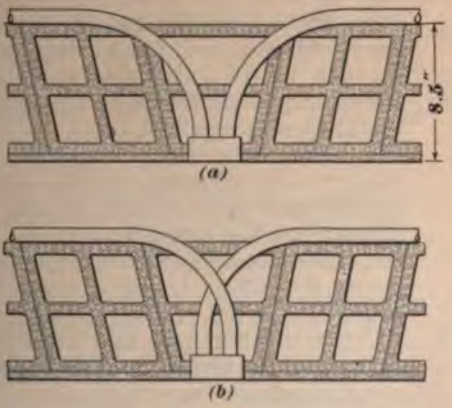


FIG. 36.

installation, a ground detector should be installed at the main distribution center, so that a ground may be easily located and lifted.

63. While a conduit system is considered merely as a "system of raceways" for the wires, if it is properly installed, all joints firmly made, and an efficient ground provided, it serves the purpose also of an additional protection. No ground can then occur anywhere in the concealed wiring in the building except upon the conduit, and if that is grounded to the earth, it cannot do any damage. If two grounds should occur upon opposite sides of the line, a "dead" short circuit is formed through the walls of the iron pipe. This will blow the fuses on the lines affected, discon[illegible]ing them, but doing no other damage. The iron pipe also has the effect of choking back any possible lightning stroke upon the line, thus affording additional protection to the lamps and fixtures.

64. Screw joints between various lengths of pipe and between pipes and junction boxes and cut-out cabinet frames are to be preferred to all other kinds of joints, because they are more secure and afford better electrical contact. To secure them in an entire system, it is necessary to use a few right-hand and left-hand couplings or a few unions. Where unions are used, they should preferably be of brass, because brass gives better contact at the sliding joints than iron. Right-hand and left-hand couplings are also used. In most cases, however, instead of a union or right-hand and left-hand coupling, the thread is cut well back on one piece, the coupling screwed on and afterwards screwed back over the other piece.

But owing to the difficulty of installing screw joints in all places, and because other joints are easier to make and require less expensive fittings (though not so good), many systems have been designed in which other kinds of joints are relied on. Whatever system is used, however, the workman must not shirk the duty of making good pipe connections, which are as important as soldered joints on the wires.

65. Flexible Armored Conduit.—In order to avoid joints and make the conduit cheaper and easier to install, flexible armored conduits have recently been brought forward. Fig. 37 shows a piece of the Greenfield conduit, showing the method of connecting it to a junction box. This conduit is made of steel ribbon wound spirally. It affords a good protection to the wire against mechanical injury, but it is not waterproof. It is, therefore, inferior to the iron conduit for damp places or where the conduit has to be laid in concrete. This conduit may be used for fished work, but is not allowable for a regular conduit system.

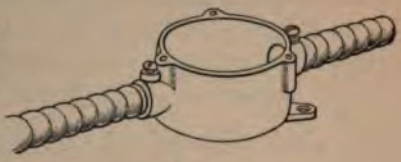


FIG. 37.

66. Economy of Space in Conduit Systems.—In those places where very many circuits are to be run, as, for example, in a partition or along one wall, it is often impossible to find space enough for all the wires and at the same time keep them the distance apart required by the Underwriters. In such cases, they may be run in conduits and placed compactly together side by side.

Where the walls on which the wires are to be concealed are of brick or stone or other masonry, a conduit system offers the only method of concealing the wires that is at once practicable, economical, and permanent. It is the system to adopt for all concealed work in new fireproof buildings and in all other new buildings except those where most of the walls and partitions are of frame covered with lath and plaster, leaving ample space and easy work for knob-and-tube construction.

In large buildings where there are to be many electric conduits, architects usually provide channels in the brickwork in which the conduits can be placed, so as to bring them behind the surface of the brick without having to cut the brick with a chisel after it is in place, which is a laborious and objectionable method.

67. Drawing Wires in Conduits.—When the wires are to be drawn into conduits, it is a good plan to blow soapstone through first, as it makes the wire slide through easier

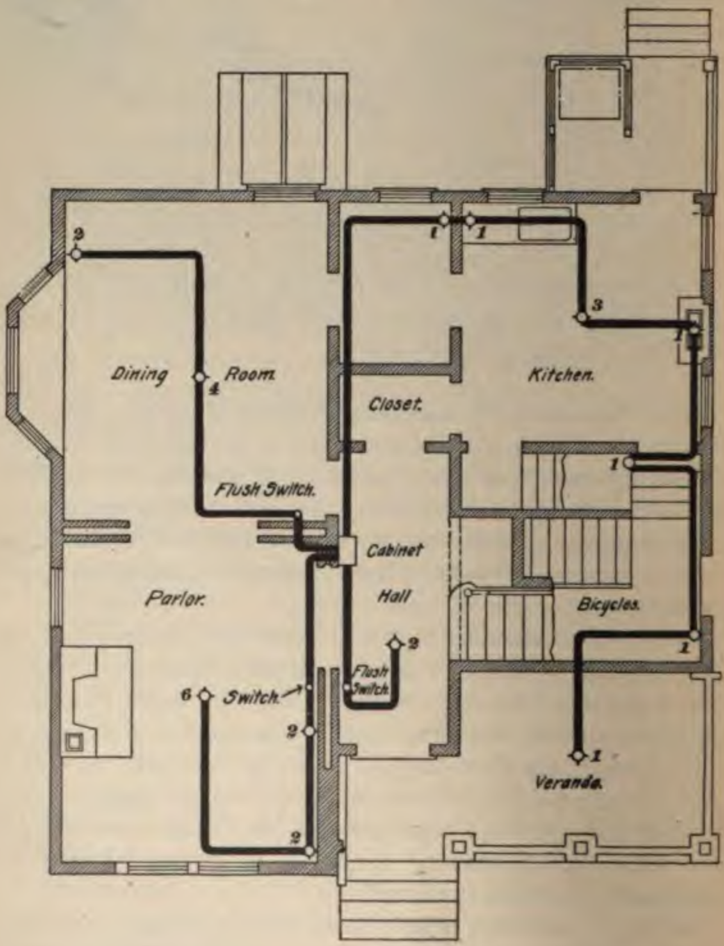


FIG. 38.

and take the ells better. A "snake" is first run through the tube and the wire pulled through by means of it. The *snake* usually consists of a steel ribbon about ⅛ inch wide with a ball about ¼ inch diameter on the end. If the conduit has many turns, it is advisable to use a coiled spiral spring about ¼ inch diameter and 6 or 8 inches long with a ball on one end and the other end fastened securely to the steel ribbon. The end with the piece of spring is pushed in first and the spring passes around the turns easily.

68. Fig. 38 shows one floor of a dwelling house wired with conduits. The numbers on the various outlets indicate the number of lamps supplied. The wiring is carried out on the loop system, and it will be noticed that no branches are taken off between outlets. Four circuits are used in order that there may not be more than ten lamps on any one circuit.

WOODEN MOLDINGS.

69. Wooden moldings are used to a great extent in running wires over woodwork, on walls, door and window frames, and other places where they cannot otherwise be well concealed. Moldings put up on ceilings or walls should be arranged symmetrically, so as to disguise their purpose, or at least not disfigure a room, even though it may be necessary to put up blank or empty molding for this purpose. Work of this kind is confined almost exclusively to old buildings. The following rules relate to these moldings:

Wooden Moldings—

a. Must have both outside and inside at least two coats of waterproof paint or be impregnated with a moisture repellent.

b. Must be made of two pieces, a backing and capping so constructed as to thoroughly encase the wire and provide a ½-inch tongue between the conductors and a solid backing that, under the grooves, shall not be less than ⅜ inch in thickness, and must afford suitable protection from abrasion.

It is recommended that only hardwood molding be used.

Wires—

For molding work:

Must have *approved* rubber-insulating covering.

Must never be placed in molding in concealed or damp places or where the difference of potential between any two wires in the same molding is over 300 volts.

70. Irresponsible parties sometimes run weather-proof wire in moldings. This practice is dangerous, for in molding work there is practically no insulation except that on the wire, if the molding damp; while in cleat and tube work there is an air and in conduit work an iron pipe, as an additional tion. Moreover, a wire with an air space or an iron ket around it cannot do much damage even if it ome very hot; but a wire embedded in wood if overlo essively will char and possibly set fire to the wood e heat cannot easily be dissipated. Dampness is t enemy of molding work.

FIG. 39.

However, where hardwood moldings and rubber-covered wires of sufficient size are used in places always dry, this kind of work is quite safe and is very much in vogue at the present day. Moldings are especially convenient in running border lights around the walls of rooms, where lamps are placed a foot or so apart, and in wiring show windows for temporary displays, and other work of a semi-permanent nature. Moldings are made in a variety of styles, some of which are ornamental and nicely finished to match the trimmings of the rooms in which they are used. Fig. 39 shows a typical two-wire molding that conforms to the Underwriters' requirements, since it has the backing *a* and capping *b*.

TESTS.

71. After a job of wiring has been completed, **tests** should be made to see if all connections are correct and also if there are any grounds or crosses between the wires. All circuits should be tested before fixtures of any kind are put up, and each fixture should be tested carefully before it is put in place. Fixtures when received from the factory are not usually wired, and connecting the sockets, etc. must be done before they are put in place. If this is not carefully done, the fixture wire is apt to become grounded; hence, the necessity of testing out fixtures before they are put into position. For most of this testing a magneto-bell is used. This is a small hand, electric generator connected with a bell similar to the call bell on a telephone. Fig. 40 shows a portable magneto made for testing work; *t*, *t'* are the terminals to which wires are attached in order to test any circuit. When a circuit is established between *t*, *t'*, the bell rings. These instruments are made of various capacities designed to ring the bell through resistances of 5,000 to 10,000 ohms, or more.

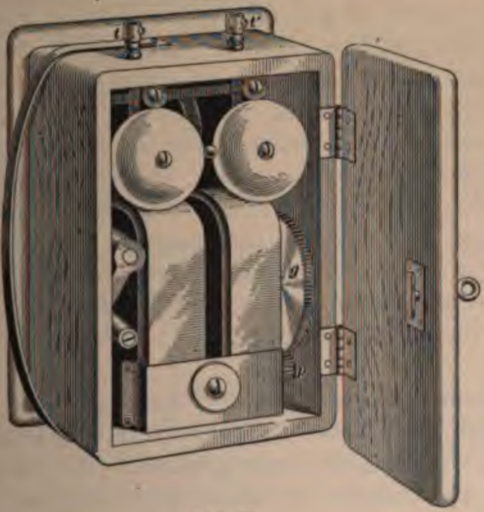


FIG. 40.

72. Each branch circuit should be tested individually with the magneto by connecting it to the terminals of the circuit at the panel board or cut-out. The wires at all the outlets should be separated and the circuit rung up. If no ring is obtained, it shows that there is no cross between the wires. The wires coming out of each outlet should then be touched together in turn and also their corresponding switch outlets, if there are any, to see if the connections to the outlets are all right. After each outlet is rung up, its wires should be left separated. Each side of the circuit should then be tested for grounds. If it is a conduit system, one terminal of the magneto should be connected to the sheathing and the other to each side of the circuit in turn. If no ring is obtained on either side, it shows that the wire is clear of grounds. If a ring is obtained, the ends should be carefully examined, and if necessary the wire must be drawn out and examined. In knob-and-tube work the method of testing is practically the same, only in testing for grounds one side of the magneto may be connected to a gas or water pipe. Each fixture should be subjected to similar tests, and after all the fixtures are in place, the system as a whole should be tested.

73. Underwriters' Tests. — An insurance inspector usually tests each branch line with a magneto for continuity, short circuits, and grounds. He then usually counts up the number of lamps on each circuit and notes the sizes of wire used to see that no wire is overloaded when all the lamps are on. Concealed work must be inspected before the lath and plaster are put on, otherwise it will not be passed without special investigation; this means tearing up floors and walls, which is expensive, to say the least.

In most installations, where the inspector has no reason to suspect that any faulty material has been used, he is able to satisfy himself by these tests and by examining the work with his eye; in fact, in many cases an ocular inspection is the only inspection made by the authorities, if they are satisfied that the contractor is honest and has made the other necessary tests.

74. Where more particular attention is given to a piece of work or where it is desired to learn whether an old installation or one not properly inspected at the time the work was done is up to the standard of safety, the insulation resistance is measured.

> **Insulation Resistance.**—
>
> The wiring in any building must test free from grounds; i. e., the complete installation must have an insulation between two separate conductors and also between all conductors and the ground (not including attachments, sockets, receptacles, etc.) of not less than the following:

Up to	5 amperes	4,000,000 ohms.
Up to	10 amperes	2,000,000 ohms.
Up to	25 amperes	800,000 ohms.
Up to	50 amperes	400,000 ohms.
Up to	100 amperes	200,000 ohms.
Up to	200 amperes	100,000 ohms.
Up to	400 amperes	25,000 ohms.
Up to	800 amperes	25,000 ohms.
Up to	1,600 amperes	12,500 ohms.

> All cut-outs and safety devices should be in place when the above test is made.
>
> Where lamp sockets, receptacles, and electroliers, etc. are connected, one-half of the above will be required.

Where lamps or other devices are suspected of taking more current than they should or where the load on any line is, for any reason, in doubt, the current should be measured with an ammeter.

MEASUREMENT OF DROP IN VOLTS.

75. If the current can be turned on in order to make a test of the drop in voltage, the best way is to use a voltmeter and determine the actual drop on each line at full load. With an ordinary voltmeter, the best method is to have two pairs of test cords and plugs connected to a double-pole double-throw switch. One pair of test cords should run to the distribution center; the other should run to the fixture to which the drop is to be determined. The switch should be so connected to the voltmeter that a reading of the voltage at the end of one pair of cords can be taken one instant and that at the end of the other pair of cords the next. The difference is the drop in volts on that line. All of the lamps should be turned on while the measurements are being taken, and several sets of readings should be made, because currents supplied from central stations suffer variations in voltage.

MARINE WORK.

76. Wiring on board ships is subjected to some special conditions and therefore requires special treatment. The first important condition not usually met with on land is the motion of the ship, which makes it necessary to avoid all forms of construction where chafing or breaking might take place. The second important peculiarity is the constant dampness of the atmosphere. For these and other reasons a separate code has been prepared for marine work, from which the following rules are selected. They embody the chief points in which marine work differs from other work.

Wires—

a. Must be supported in approved molding or conduit except at switchboards and portables.

Special permission may be given for deviation from this rule in dynamo rooms.

b. Must have no single wire larger than No. 12 B. & S. Wires to be stranded when greater carrying capacity is required. No single solid wire smaller than No. 14 B. & S. except in fixture wiring to be used.

Stranded wires must be soldered before being fastened under clamps or binding screws, and when they have a conductivity greater than No. 10 B. & S. copper wire, they must be soldered into lugs.

c. Splices or taps in conductors must be avoided as far as possible. Where it is necessary to make them, they must be so spliced or joined as to be both mechanically and electrically secure without solder. They must then be soldered, to insure preservation, covered with an insulating compound equal to the insulation of the wire, and further protected by a waterproof tape. The joint must then be coated or painted with a waterproof compound.

Wires for Molding Work—

a. Must have an *approved* insulating covering.

The insulation for conductors, to be approved, must be at least $\frac{3}{32}$ inch in thickness and covered with a substantial waterproof and flame-proof braid.

The physical characteristics shall not be affected by any change in temperature up to 200° F. After 2 weeks' submersion in salt water at 70° F., it must show an insulation resistance of 1 megohm per mile after 3 minutes' electrification with 550 volts.

b. Must have when passing through water-tight bulkheads and through all decks a metallic stuffing tube lined with hard rubber. In case of deck tubes, they shall be boxed near deck to prevent mechanical injury.

c. Must be bushed with hard-rubber tubing $\frac{1}{8}$ inch in thickness when passing through beams and non-water-tight bulkheads.

Wires for Conduit Work—

a. Must have an *approved* insulating covering.

The insulation for conductors for use in lined conduits, to be approved, must be at least $\frac{3}{32}$ inch in thickness and be covered with a substantial waterproof and flame-proof braid. The physical characteristics shall not be affected by any change in temperature up to 200° F.

After 2 weeks' submersion in salt water at 70° F., it must show an insulation resistance of 1 megohm per mile after 3 minutes' electrification with 500 volts.

For unlined metal conduits, conductors must conform to the specifications given for lined conduits, and in addition have a second, outer, fibrous covering at least $\frac{1}{32}$ inch in thickness and sufficiently tenacious to withstand the abrasion of being drawn through the metal conduit.

b. Must not be drawn in until the mechanical work on the conduit is completed and the same is in place.

c. When run through coal bunkers, boiler rooms, and where they are exposed to severe mechanical injury, must be encased in approved conduit.

TABLE VI.

of Capacity of Wires for Marine Work.

B. & S. G.	Area Actual C. M.	Number of Strands.	Size of Strands B. & S. G.	Amperes.
19	1,288			
18	1,624			3
17	2,048			
16	2,583			6
15	3,257			
14	[illegible]			12
12	[illegible]			17
	[illegible]	[illegible]	19	21
	[illegible]	[illegible]	18	25
	[illegible]	[illegible]	17	30
	[illegible]	[illegible]	16	35
	[illegible]	[illegible]	15	40
	[illegible]	[illegible]	18	50
	[illegible]	[illegible]	17	60
	[illegible]	[illegible]	16	70
	[illegible]	[illegible]	18	85
	[illegible]	[illegible]	17	100
	[illegible]	[illegible]	18	120
	[illegible]	[illegible]	17	145
	[illegible]	[illegible]	16	170
	[illegible]	[illegible]	15	200
	250,527	61	14	235
	296,387	91	15	270
	373,737	91	14	320
	413,639	127	15	340

Portable Conductors—

Must be made of two stranded conductors, each having a carrying capacity equivalent to not less than No. 14 B. & S. wire, and each covered with an approved insulation and covering.

Where not exposed to moisture or severe mechanical injury, each stranded conductor must have a solid insulation at least $\frac{1}{32}$ inch in thickness and must show an insulation resistance between conductors and between either conductor and the ground of at least 1 megohm per mile after 1 week's submersion in water at 70° F. and after 3 minutes' electrification with 500 volts, and be protected by a slow-burning, tough-braided, outer covering.

Where exposed to moisture and mechanical injury—as for use on decks, holds, and firerooms—each stranded conductor shall have a solid insulation, to be approved, of at least $\frac{1}{32}$ inch in thickness and be protected by a tough braid. The two conductors shall then be stranded together, using a jute filling. The whole shall then be covered with a layer of flax, either woven or braided, at least $\frac{1}{32}$ inch in thickness, and treated with a non-inflammable, waterproof compound. After 1 week's submersion in water at 70° F., at 550 volts, and a 3 minutes' electrification, must show an insulation between the two conductors or between either conductor and the ground of 1 megohm per mile.

Wooden Moldings—

a. Must be made of well-seasoned lumber and be treated inside and out with at least two coats of white lead or shellac.

b. Must be made of two pieces, a backing and a capping, so constructed as to thoroughly encase the wire and provide a ½-inch tongue between the conductors and a solid backing that, under the grooves, shall not be less than ⅜ inch in thickness.

c. Where molding is run over rivets, beams, etc., a backing strip must first be put up and the molding secured to this.

d. Capping must be secured by brass screws.

Cut-Outs.—

a. In places such as upper decks, holds, cargo spaces, and firerooms, a water-tight and fireproof cut-out may be used, connecting directly to mains when such cut-out supplies circuits requiring not more than 660 watts energy.

b. When placed anywhere except on switchboards and certain places, as cargo spaces, holds, firerooms, etc., where it is impossible to run from center of distribution, they shall be in a cabinet lined with fire-resisting material.

c. Except for motors, searchlights, and diving lamps, shall be so placed that no group of lamps requiring a current of more than 6 amperes shall ultimately be dependent on one cut-out.

A single-pole covered cut-out may be placed in the molding when same contains conductor supplying circuits requiring not more than 220 watts energy.

Fixtures—

a. Shall be mounted on blocks made from well-seasoned lumber treated with two coats of white lead or shellac.

b. Where exposed to dampness, the lamp must be surrounded by a vapor-proof globe.

c. Where exposed to mechanical injury, the lamp must be surrounded by a globe protected by a stout-wire guard.

WIRING ESTIMATES.

77. It is difficult to lay down any reliable rules to be used in estimating the cost of a proposed wiring job. As when estimating in other lines of work, experience must largely be relied on. The prices of labor and material vary so widely in different sections of the country that any general rules might lead to very inaccurate results. Moreover, these prices are always fluctuating. One frequently sees statements to the effect that certain kinds of wiring can be done for so much per lamp or so much per outlet, but it is evident that while such figures might be fairly correct so far as the average of a large number of installations is concerned, they might be far from correct when applied to individual cases.

78. The only way in which to obtain a fairly close estimate of the cost of a given installation is to prepare plans and lay out the circuits, marking the size of the wire and the capacity of the various switches and cut-outs required. By laying out these plans, the amount of wire, conduit, and other material required may be arrived at quite closely. The number of switches, cut-outs, etc. can be counted up and their cost estimated. In measuring the length of the circuits, do not forget to take into account the wire and material necessary for running up and down walls to switches or outlets. Margin should be allowed for such material as tape, solder, etc. The labor item will depend largely on whether the building to be wired is an old one or one in the process of construction, also on the style of wiring used, so that the labor item can only be determined from a careful inspection of the premises to be wired and experience on work of a similar class. An ordinary two-story dwelling house wired on the concealed knob-and-tube system will require about 6 days' labor of a man and helper. This is for a medium sized house. Some small houses will require less than this. Old houses require a much larger expenditure of labor, because there is liable to be considerable molding work to be done.

79. As stated before, it is unsafe to assume a certain cost per outlet in figuring on a job of wiring unless one has been doing considerable work of a certain class. As a rough guide, however, it may be stated that ordinary dwellings wired on the concealed knob-and-tube plan will cost from $2.00 to $3.00 per outlet. This, of course, does not include the fixtures, but should cover the cost of snap switches and porcelain cut-outs. Ordinary exposed wiring can usually be run for $1.00 to $1.75 per drop, including rosettes, cord, and sockets, though, of course, very much depends on how closely the lights are grouped. It is evident that if the lamps are scattered very much, the cost of wire, porcelain fittings, and labor will be comparatively high, and this will increase the cost per drop. Wiring with iron-armored conduit is expensive, but it is substantial. It is difficult to give any figures as to the cost per outlet. For small installations, it will probably cost from $5.00 to $6.00 per outlet; in large installations, the cost will be somewhat less. The student must remember that these figures are approximate only. The cost in different localities might vary widely from the above, and the only way to make a fairly close estimate is to lay out the circuits, make a list of the material needed, and estimate their cost and the probable labor required.

INTERIOR WIRING.

(PART 3.)

COMBINING SEVERAL WIRING SYSTEMS.

STORE LIGHTING.

1. A large electric-light installation generally requires many kinds of wiring, and there are usually special conditions that determine what kind of work is to be done in each locality. As an example, we will take the wiring system of a certain department store as it was actually put in.

After a careful study of the conditions existing, the managers of the store concluded that enclosed-arc lamps were best suited for the general illumination of their stores, and that incandescent lamps should be installed for use at desks, in closets and warerooms, and occasionally in show windows. Accordingly, the premises were wired for 250 enclosed-arc lamps and 500 incandescent lamps at 110 volts.

Separate feeder wires were run to each of the ten departments. The dynamos were installed in the engine room in the subbasement, one machine capable of supplying current for one-third of the lamps to be used when the load was light, and one generator capable of operating two-thirds of the lamps, and some small motors. When the entire load was on, the two generators operated in multiple.

For notice of copyright, see page immediately following the title page.

system in this case involved no saving in the lines, as that system extended only to the main switchboard, beyond which the two-wire system was used.

3. The feeder cables were run from the engine room to the centers of distribution in each of the various departments, in iron-armored conduits, one cable to a conduit. Cables and not wires were used, because heavy, solid conductors cannot be drawn into conduits with bends in them. These conduits were put together with screw couplings, with corner boxes of special design at each elbow, as the cables were very heavy. In the basement the conduits were all connected together by locknuts and a bus-bar, which was grounded to the water main back of the main valve on the automatic-sprinkler system by an iron rod, which was inserted in the water pipe like a tap. This afforded an excellent ground.

4. Cut-out cabinets were installed in each department. When in conspicuous places, they contained marble tablets upon which were mounted lugs to receive fuses. Enclosed fuse links were used. A switch was provided on the tablet for each circuit. All connecting wiring was done on the back of the board and was thus concealed. The tablets were mounted in hardwood cabinets with plate-glass doors that opened by sliding downwards like a window sash. In less conspicuous places, the cabinets were provided with hinged wooden doors, were lined with asbestos, and provided with porcelain link fuse cut-outs of the open-fuse type. For each enclosed-arc lamp a separate branch line was run from the nearest cut-out cabinet. Large departments were provided with several cut-out cabinets connected to the same pair of feeders.

5. The branch lines were run in various ways; some of them were run in pipes, some were run in molding, and some were run open. Where they were placed in pipes, twin conductors were used and the lamps were hung from the pipe ends by means of an insulating joint. All the branch pipes were connected together and to the feeder lamps of various colors, and are also usually provided with dimmers. Therefore, the stage switchboard of a large theater is quite a complicated affair compared with the distribution closets used in ordinary work.

In cases where there are a large number of borders of incandescent lamps, it is inconvenient to divide them into circuits of only 660 watts, and permission can usually be obtained from the Underwriters to place more lamps on such circuits if special care is taken.

9. Stage dimmers are of two kinds, *resistance boxes* and *reactive coils*. The latter are more economical, but can be used with alternating currents only. Care must be taken to locate resistance boxes where they can be kept cool by the circulation of fresh air. **Equalizers** are used to regulate voltages within small limits when large currents are used, as, for example, to correct unbalancing of the three-wire system. They are made of small resistance and large carrying capacity. The following Underwriters' rules relate to the installation of these appliances:

Resistance Boxes and Equalizers—

> Must be equipped with metal or with other non-combustible frames.
>
> The word "frame" in this section relates to the entire case and surroundings of the rheostat, and not alone to the upholding supports.

Reactive Coils.—

> Reactive coils must be made of non-combustible material, mounted on non-combustible bases, and treated, in general, like sources of heat.

Most of the dimmers in common use consist of a resistance split up into a number of sections, so that the amount of resistance in series with the lamps may be varied. They are made in a number of different forms, some of them being arranged so that their operating handles interlock so that they may be operated singly or together in any desired combination. Dimmers are, of course, connected *in series* with the circuits that they are intended to control.

them and 112.5 volts at the terminals. This can only be accomplished by running the lines in opposite directions and having them change in size often enough to secure practically uniform drop per foot. Fig. 2 (*a*) illustrates such an arrangement, and (*b*) shows the same thing drawn in a straight line instead of a square. This is sometimes called the *anti-parallel* method of feeding.

12. There will be a lamp for every foot. There will be required 40 branches of No. 14 wire, with 25 lamps on each branch, as shown in Fig. 2 (*b*). Weather-proof wall receptacles will be used. The total length of wire in the mains is 2,000 feet. The length of wire to any given branch is 1,000 feet; hence, the rate of drop must be 12.5 volts per 1,000 feet. On account of the method of feeding from each end, it is easily seen in Fig. 2 (*b*) that the length of wire through which the current flows to any point *d* must be 1,000 feet. The currents that various wires will carry with a drop of 12.5 volts are as follows:

Size of Wire.	*Volts Drop.*		*Resistance per 1,000 Feet.*		*Amperes.*
No. 14	12.5	÷	2.521	=	4.96
No. 12	12.5	÷	1.586	=	7.88
No. 10	12.5	÷	.997	=	12.5
No. 8	12.5	÷	.627	=	19.9
No. 6	12.5	÷	.394	=	31.7
No. 5	12.5	÷	.313	=	39.9
No. 4	12.5	÷	.248	=	50.4

The amperes for larger wires can be be found by consulting the tables in *Interior Wiring*, Part 2.

Since the lamps are to be 8 candlepower, there will be about 1 ampere for every 4 lamps, and consequently for every 4 feet of line (2 wires). In making up a conductor to have nearly uniform drop, it will be necessary for us to compromise for all points that do not exactly correspond with the above-calculated current values. For instance, if we join No. 12 wire to No. 14 wire, it must be at a point where there is between 4.96 and 7.88 amperes. If we select lengths of wire that will bring this joint half way between the points where the wires exactly correspond, it will be near enough. We then will have results as given by the following table:

Size of Wire.	Amperes Giving 12.5 Volts per 1,000 Feet.	Corresponding Distance from End of Line.	Distance of End of Wire from End of Line.	Length of Wire to be Used.
14	4.96	20	26	26
12	7.88	32	41	15
10	12.5	50	65	24
8	19.9	80	104	39
6	31.7	127	144	40
5	39.9	160	181	37
4	50.4	202	228	47
3	63.5	254	290	62
2	80.1	320	362	72
1	100.8	403	457	95
0	127.5	510	576	119
00	160.3	641	724	148
000	201.6	806	915	191
0000	255.1	1,020	1,000	85

In the above table the second column is obtained by dividing the volts drop (12.5) by the resistance per 1,000 feet of the various sizes of wire. The third column is found by taking the approximate value of the current multiplied by 4 because there is 1 ampere for every 4 feet of cornice. The fourth column is obtained by taking one-half the difference between the succeeding quantities in column 3 and adding this difference to the quantity in column 3. For example, at a point 20 feet from the end the current is 4.96 amperes and at a point 32 feet from the end it is 7.88 amperes. As stated above, we will select lengths of wire that will bring the joints between the different sizes of wire midway between the points where the wires correspond.

Hence, in the first case if we have a current of 7.88 amperes 32 feet from the end and a current of 4.96 amperes 20 feet from the end, the joint will be $20 + \frac{32 - 20}{2} = 26$ feet from the end and 26 feet of No. 14 wire will be required. Also in the case of the No. 8 and No. 6 wires, we have 19.9 amperes 80 feet from the end and 31.7 amperes 127 feet from the end; hence, the joint between the two sizes will be $80 + \frac{127 - 80}{2} = 103.5$ feet from the end. In the table, the nearest even feet are given, so that this is taken as 104. In the case of the 0000 wire, the distance from the end of the line corresponding to a drop of 12.5 volts works out 1,022 feet, though, of course, there would not be quite as large a current as 255.1 amperes because the line cannot be longer than 1,000 feet. This quantity is, however, used in determining the distance (915 feet) of the end of the 000 wire from the end of the line. The distance of the end of the 0000 wire must, of course, be 1,000 feet because the cornice is 1,000 feet long. The lengths in column 5 are obtained by subtracting the successive values of column 4, for example 65 — 41 = 24, 104 — 65 = 39, etc.

13. Cut-outs of the following amperes capacity would have to be installed:

15 amperes, to protect Nos. 14, 12, and 10.
65 amperes, to protect Nos. 8, 6, 5, 4, and 3.
130 amperes, to protect Nos. 2, 1, and 0.
160 amperes, to protect No. 00.
250 amperes, to protect Nos. 000 and 0000.

This statement assumes that weather-proof wire is to be used. Fig. 3 is a diagram of a portion of the wiring in place, showing the connections of cut-outs.

14. Another method of wiring for temporary work is to put up wires on the feeder system just large enough to carry the current, and then calculate the drop and install lamps of the required voltage. This is a simple and very cheap method. In the case of the border lamps just considered, if wired in this way, we could use eight pairs of feeders of No. 10 wire, with 125 lamps per feeder. If we arrange the feeders as shown in Fig. 4, the lengths of these feeder lines and the drop on each would then be roughly as follows, if each lamp required $\frac{1}{4}$ ampere. Current in each feeder is $\frac{125}{4}$ amperes, and No. 10 wire has a resistance of about 1 ohm per thousand feet. The approximate length of the feeders will be as given below:

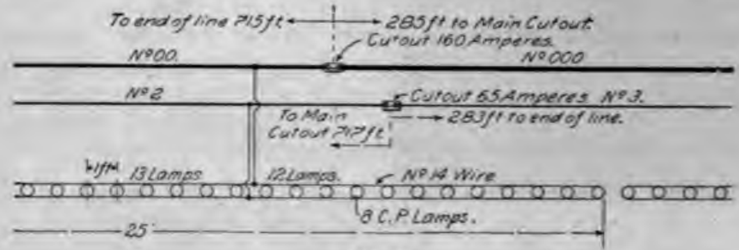


FIG. 3.

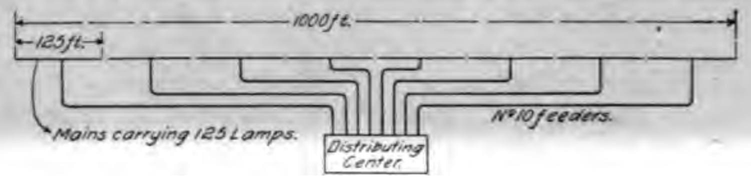


FIG. 4.

2 lines 425 feet (2 wires) long, 26.6 volts drop.
2 lines 300 feet (2 wires) long, 18.8 volts drop.
2 lines 175 feet (2 wires) long, 10.9 volts drop.
2 lines 50 feet (2 wires) long, 3.1 volts drop.

The drop in the first case $= \frac{125}{4} \times .425 \times 2 = 26.6$. The others are found in a similar manner. In the distribution, about 1 volt would be lost. Consequently, if 125 volts are supplied, the lamps should have voltages of 97, 105, 113, and 121 if each lamp requires $\frac{1}{4}$ ampere.

15. There are many other methods or plans by which such a building as this could be wired for a large drop and still be furnished with uniform and steady light. The suggestions here given are merely to set the student thinking about the matter of saving material. By making every installation a matter of special study, until he has thoroughly mastered every detail of the business, he will discover many ways of economizing labor and material that cannot be brought to his attention in any other way. Before using any unusual method, however, he should make certain that there is no objection on the part of the Underwriters or of the Fire Department to what he proposes to do.

HIGH-POTENTIAL SYSTEMS.

16. The foregoing rules have applied to systems using 550 volts or less. For pressures over 550 volts, the following rules apply:

HIGH-POTENTIAL SYSTEMS.

550 TO 3,500 VOLTS.

> *Any circuit attached to any machine or combination of machines which develops a difference of potential between any two wires of over 550 volts and less than 3,500 volts shall be considered as a high-potential circuit and as coming under that class, unless an approved transforming device is used which cuts the difference of potential down to 550 volts or less.*

Wires—

> *a.* Must have an *approved* rubber-insulating covering.
>
> The thickness of the insulating walls must not be less than those given in the following table for B. & S. gauge sizes:
>
> From 14 to 1. inclusive, $\frac{3}{32}$".
> From 0 to 500,000 C. M., $\frac{3}{32}$" covered by a tape or a braid.
> Larger than 500,000 C. M., $\frac{4}{32}$" covered by a tape or a braid.

The requirements as to insulation and break-down resistance for wires for low-potential systems shall apply, with the exception that an insulation resistance of not less than 300 megohms per mile shall be required.

b. Must be always in plain sight and never encased except where required by the Inspection Department having jurisdiction.

c. Must be rigidly supported on glass or porcelain insulators, which raise the wire at least 1 inch from the surface wired over, and must be kept about 8 inches apart.

d. Must be protected on side walls from mechanical injury by a substantial boxing, retaining an air space of 1 inch around the conductors, closed at the top (the wires passing through bushed holes) and extending not less than 7 feet from the floor. When crossing floor timbers in cellars or in rooms where they might be exposed to injury, wires must be attached by their insulating supports to the under side of a wooden strip not less than ½ inch in thickness.

17. It is never advisable to bring high-potential wires into a building when it can be avoided. The danger to life due to their presence is greater than the fire hazard. An arc on a high-potential circuit carrying much current, once started, will continue to burn even when the points between which it plays are separated several inches; and a lightning discharge can easily start such an arc. High-potential systems of over 500 volts are usually alternating. Series-arc lighting circuits are the only important continuous-current high-potential circuits much used in the United States. With the exception of arc lamps, it is seldom necessary to bring any high-potential wires inside of buildings. Where alternating current is used, the line pressure is lowered by means of transformers, and it is never necessary to bring the high-pressure wires farther within than to substations or transformer rooms.

18. Transformers.—The ordinary alternating-current transformer consists of two separate coils of wire wound on an iron core built up of thin sheets of iron. One of these coils, the *primary*, has a comparatively large number of turns and is connected to the high-pressure line. The other coil, the *secondary*, has a small number of turns and is connected to the lamps or other devices to be supplied with current. The high-pressure current flows through the primary and sets up an alternating magnetism through the secondary and induces an E. M. F. that is proportional to the ratio of the number of turns in the secondary coil to the number of turns in the primary. For example, if the primary had 500 turns and the secondary 50, the secondary voltage would be $\frac{50}{500}$, or $\frac{1}{10}$ the primary voltage, and if the primary were supplied at 1,000 volts, the secondary would deliver 100 volts. The following rules relate to transformers. Transformers of good reliable manufacture will stand all the tests named, but some of the old types made a number of years ago will not. Special attention should be paid to the rules governing the installation of transformers in buildings. Cut-outs on such circuits must be of some pattern especially designed and approved for the purpose. Ordinary fuse blocks should not be used for high voltages.

19. Rules Relating to Transformer Construction and Installation.—

Transformers—

a. Must not be placed in any but metallic or other non-combustible cases.

b. Must be constructed to comply with the following tests:

1. Shall be run for 8 consecutive hours at full load in watts under conditions of service, and at the end of that time the rise in temperature, as measured by the increase of resistance of the primary coil, shall not exceed 135° Fahrenheit.

2. The insulation of transformers when heated shall withstand continuously for 5 minutes a difference of potential of 10,000 volts (alternating) between primary and secondary coils and between the primary coils and core, and a no-load "run" at double voltage for 30 minutes.

c. Must not be placed inside of any building, excepting central stations, unless by special permission of the Inspection Department having jurisdiction.

d. Must not be attached to the outside walls of buildings, unless separated therefrom by substantial supports.

(*When permitted inside buildings.*)

a. Must be located at a point as near as possible to that at which the primary wires enter the building.

b. Must be placed in an enclosure constructed of or lined with fire-resisting material; the enclosure to be used only for this purpose, and to be kept securely locked and access to the same allowed only to responsible persons.

c. Must be effectually insulated from the ground and the enclosure in which they are placed must be practically air-tight, except that it shall be thoroughly ventilated to the outdoor air, if possible, through a chimney or flue. There should be at least 6 inches of air space on all sides of the transformer.

20. The greatest danger to be feared in the use of transformers is the grounding of the primary upon the secondary wires. This may occur either on account of a breakdown of the insulation under working conditions or because of lightning striking the primary wires. Efficient protection against lightning is an essential part of the out-of-door and central-station equipment.

WIRING FOR ARC LAMPS.

21. Constant-Potential Arc Lamps.—The use of arc lamps in multiple on low-potential circuits has already been considered. Wiring for these lamps is done in practically the same way as for incandescent lamps, so that no special comment is necessary. The following special rules relate to arc lamps operated on low-pressure circuits; a few rules relating to electric heaters are also given, as they belong to the same class of work.

Arc Lights on Low-Potential Circuits—

a. Must have a cut-out for each lamp or each series of lamps.

The branch conductors should have a carrying capacity about 50 per cent. in excess of the normal current required by the lamp to provide for heavy current, required when lamp is started or when carbons become stuck, without overfusing the wires.

b. Must only be furnished with such resistances or regulators as are enclosed in non-combustible material, such resistances being treated as sources of heat. Incandescent lamps must not be used for resistance devices.

c. Must be supplied with globes and protected by spark arresters and wire netting around globe, as in the case of arc lights on high-potential circuits.

Electric Heaters—

a. Must, if stationary, be placed in a safe situation, isolated from inflammable materials, and be treated as sources of heat.

b. Must each have a cut-out and *indicating* switch; i. e., a switch to indicate whether the current is "on" or "off."

c. Must have the attachments of feed-wires to the heaters in plain sight, easily accessible and protected from interference, accidental or otherwise.

d. The flexible conductors for portable apparatus, such as irons, etc., must have an *approved* insulating covering.

e. Must each be provided with name plate, giving the maker's name and the normal capacity in volts and amperes.

22. Constant-Current Arc Lamps.—Arc lamps used for street lighting are nearly always run in series. With this arrangement the same current flows through all the lamps and this current has to be maintained at a constant value by the generator, no matter how many lights may be in operation. The voltage generated by the dynamo therefore varies with the load. For example, suppose each lamp requires 50 volts; then, if 10 lamps were in operation, the generator would have to supply a pressure of 500 volts; if 50 lamps, 2,500 volts; and so on. The current has to be forced through all the lamps in series; hence, the voltage increases directly as the load, while the current remains constant. This is just the reverse of the constant-potential system. It is easily seen that if the number of lamps is at all large, the pressure applied to the circuit has to be very high; hence, arc lamps connected to such a circuit must be treated as being on a high-pressure system and wired up accordingly. Series-arc lamps are used for indoor illumination, though not as extensively as they once were.

23. In all constant-potential installations, protective devices are installed to open the circuit whenever the lines are overloaded or the apparatus does not operate properly. *In constant-current working, the circuit must never be opened while the dynamo is running.* The protective devices used on constant-potential working must, therefore, never be installed on constant-current circuits.

All series-arc apparatus is thrown out of circuit by shunting or short-circuiting the main circuit before opening the lines upon which the apparatus is connected; in other words, the following rule must be complied with:

Switches—

> Must, for constant-current systems, close the main circuit and disconnect the branch wires when turned "off"; must be so constructed that they shall be automatic in action, not stopping between points when started, and must prevent an arc between the points under all circumstances. They must indicate, upon inspection, whether the current be "on" or "off."

24. The general method of installing arc-lighting wires is similar to that used in other open work, except that the wires must be rubber-covered and mounted at least 8 inches apart. They must also be very thoroughly protected against accidental contact with anything not intended to connect with them. The following rules apply to the installation of the wires:

Wires for Use on Constant-Current Series-Arc Systems—

a. Must have an *approved* rubber insulating covering.

b. Must be arranged to enter and leave the building through an *approved* double-contact service switch, mounted in a non-combustible case, kept free from moisture and easy of access to police or firemen. So-called "snap switches" must not be used on high-potential circuits.

c. Must always be in plain sight and never encased except when *required* by the Inspection Department having jurisdiction.

d. Must be supported on glass or porcelain insulators, which separate the wire at least 1 inch from the surface wired over, and must be kept *rigidly* at least 8 inches from each other, except within the structure of lamps, on hanger boards, in cut-out boxes, or like places, where a less distance is necessary.

e. Must, on side walls, be protected from mechanical injury by a substantial boxing, retaining an air space of 1 inch around the conductors, closed at the top (the wires passing through bushed holes), and extending not less than 7 feet from the floor. When crossing floor timbers in cellars or in rooms, where they might be exposed to injury, wires must be attached by their insulating supports to the under side of a wooden strip not less than ½ inch in thickness.

The size of arc wires must not be smaller than that required by the Underwriters for the current used; but the wires should be much larger, on account of the loss in the lines and for mechanical strength. They should be of the same size as the wires used by the lighting company in its outside work, but must be rubber-covered, not weatherproof.

25. The tendency is to connect more and more arc lamps on a series circuit. In the early days of electric lighting, arc machines were made to operate 1, 2, or 3 lamps. The number was increased to 30 or 50, and finally to 60, where the limit remained for a few years. But machines are now built to operate as many as 125 lamps on a single circuit, and are in quite general use, although the Underwriters prohibit the bringing of circuits of more than 3,500 volts (70 series-arc lamps) within buildings. With 45 volts at the arc and 5 volts lost on the line for each lamp, we have on a 125-lamp machine a total potential difference of 6,250 volts. A shock received through the human body from such a circuit is almost sure to be fatal. Too much care cannot be taken not only to insulate the wires and locate them out of reach, but also to insulate the lamps. They should be hung from insulated supports, and not hooks screwed into the ceiling.

Hanger Boards—

Must be so constructed that all wires and current-carrying devices thereon shall be exposed to view and thoroughly insulated by being mounted on a non-combustible, non-absorptive, insulating substance. All switches attached to the same must be so constructed that they shall be automatic in their action, cutting off both poles to the lamp, not stopping between points when started, and preventing an arc between points under all circumstances.

Arc Lamps—

a. Must be provided with reliable stops to prevent carbons from falling out in case the clamps become loose.

b. Must be carefully insulated from the circuit in all their exposed parts.

c. Must, for constant-current systems, be provided with an *approved* hand switch, also an automatic switch that will shunt the current around the carbons, should they fail to feed properly.

The hand switch to be approved, if placed anywhere except on the lamp itself, must comply with requirements for switches on hanger boards.

d. Must be carefully isolated from inflammable material.

e. Must be provided at all times with a glass globe surrounding the arc, securely fastened upon a closed base. No broken or cracked globes to be used.

f. Must be provided with a wire netting (having a mesh not exceeding 1¼ inches) around the globe, and an *approved* spark arrester, when readily inflammable material is in the vicinity of the lamps, to prevent escape of sparks, melted copper, or carbon. It is recommended that plain carbons, not copper plated, be used for lamps in such places.

Arc lamps, when used in places where they are exposed to flyings of easily inflammable material, should have the carbons enclosed completely in a globe in such manner as to avoid the necessity for spark arresters.

For the present, globes and spark arresters will not be required on so-called "inverted-arc" lamps, but this type of lamp must not be used where exposed to flyings of easily inflammable materials.

g. Where hanger boards are not used, lamps must be hung from insulating supports other than their conductors.

h. Spark arresters must so close the upper orifice of the globe that it will be impossible for any sparks thrown off by the carbons to escape.

26. Incandescent Lamps on Series Circuits.—The use of incandescent lamps connected in series for street lighting is quite extensive, but such lamps are rarely brought inside of buildings. When they are, the rules for other classes of high-potential work apply, as well as the following:

Incandescent Lamps on Series Circuits—

a. Must have the conductors installed as required by the rules for constant-current arc-lamp wiring and each lamp must be provided with an automatic cut-out.

b. Must have each lamp suspended from a hanger board by means of rigid tube.

c. No electromagnetic device for switches and no system of multiple-series or series-multiple lighting will be approved.

d. Under no circumstances can they be attached to gas fixtures.

Incandescent lamps used on series circuits must be designed and provided with fittings designed for that purpose. The rule against series-multiple connections means that a connection such as ten 52-volt lamps in multiple must not be

CURRENT REQUIRED BY MOTORS.

H. P.	Direct-Current Motors.			Alternating-Current Motors.								
				Single Phase.			Two Phase (4 Wire).			Three Phase (3 Wire).		
	110 V.	220 V.	500 V.	110 V.	220 V.	500 V.	110 V.	220 V.	500 V.	110 V.	220 V.	500 V.
1	9	4.5	2.0	14	7	3.1	6.4	3.2	1.4	7.4	3.7	1.6
2	17	8.5	3.7	24	12	5.3	11	5.7	2.5	13	6.6	2.9
3	26	13	5.6	34	17	7.5	16	8.1	3.5	19	9.3	4.1
5	40	20	8.8	52	26	11	26	13	5.5	30	15	6.4
7½	60	30	13	74	37	16	38	19	8.1	44	22	9.3
10	76	38	17	94	47	21	44	22	10	50	25	12
15	112	56	25				66	33	15	76	38	17
20	150	75	33				88	44	19	102	51	22
30	226	113	50				134	67	29	154	77	33
40	302	151	66				178	89	39	204	107	45
50	368	184	81				204	102	45	236	118	52
75	552	276	122				308	154	68	356	178	77
100	736	368	162				408	204	90	472	236	104
150	1,110	555	244				616	308	135	710	355	156
200	1,474	737	324				818	409	180	940	470	208

placed in series with a 10-ampere arc-lighting system. The burning out of 1 or 2 incandescent lamps on such a system would throw too much current on the others, burn them out, and destroy the sockets. Many other reasons forbid such connections.

WIRING FOR ELECTRIC MOTORS.

27. The wireman is frequently called upon to connect up motors. These are nearly always operated at constant potential, and the wires are installed as for other wiring of this kind. They are usually operated on 110, 220, or 500 volts direct current or on similar voltages alternating current. Alternating-current motors are usually run on either the two- or three-phase system. Care should be taken to see that the interior wiring has sufficient capacity, and in order to determine this, the current taken by the motor at full load should be known.

It is well to allow a liberal amount of current for small motors, because of their low efficiency. The efficiency of a large motor can be learned from the manufacturer; and high-grade, high-priced machines are more efficient than cheap ones. This is a most important consideration to the purchaser. For the purposes of wiring, however, it is safe to figure 90 per cent. efficiency for motors over 10 horsepower in capacity, 85 per cent. for motors of 5 horsepower or over, 80 per cent. for motors of 2 horsepower or over, 75 per cent. for motors of 1 horsepower, and lower efficiencies for motors of smaller sizes. There are 746 watts to a horsepower. Alternating-current motors take somewhat more current for the same output than those operated on direct current. The accompanying table gives the approximate value of the current in the lines for motors of various sizes and voltages. These figures would vary somewhat in individual cases, because the efficiency and other characteristics of motors vary considerably. The current taken by a motor at full load is usually given by the makers on the name plate of the machine. If it is not given, the table will serve as a guide in determining the size of wire to be used.

After the full-load current of the motor has been determined, the size of the wire is arrived at in the same way as if the wiring were being done for lights.

28. Motors should not have much drop in the wiring, or they will not regulate properly; but drop upon motor circuits does not affect motor regulation to the same extent as drop on lighting circuits affects the light. The following rules relate to the installation of motors:

Motors—

a. Must be insulated on floors or base frames, which must be kept filled to prevent absorption of moisture, and must be kept clean and dry. Where frame insulation is impracticable, the Inspection Department having jurisdiction may, in writing, permit its omission, in which case the frame must be permanently and effectively grounded.

A high-potential machine which, on account of great weight or for other reasons, cannot have its frame insulated, should be surrounded with an insulated platform. This may be made of wood mounted on insulating supports and so arranged that a man must stand upon it in order to touch any part of the machine.

In case of a machine having an insulated frame, if there is trouble from static electricity due to belt friction, it should be overcome by placing near the belt a metallic comb connected to the earth or by grounding the frame through a very high resistance of not less than 200 ohms per volt generated by the machine.

b. Must be wired under the same precautions as required by rules for wires carrying a current of the same volume and potential.

The leads or branch circuits should be designed to carry a current at least 50 per cent. greater than that required by the rated capacity of the motor to provide for the inevitable overloading of the motor at times without overfusing the wires.

c. The motor and resistance box must be protected by a cut-out and controlled by a switch, said switch plainly indicating whether "on" or "off." Where ¼ horsepower or less is used on low-tension circuits, a single-pole switch will be accepted. The switch and rheostat must be located within sight of the motor, except in such cases where special permission to locate them elsewhere is given, in writing, by the Inspection Department having jurisdiction.

d. Must have their rheostats or starting boxes located so as to conform to the requirements of other resistance boxes.

In connection with motors, the use of circuit-breakers, automatic starting boxes, and automatic underload switches is recommended, and they *must* be used when required.

e. Must not be run in series-multiple or multiple-series, except on constant-potential systems, and then only by special permission of the Inspection Department having jurisdiction.

f. Must be covered with a waterproof cover when not in use, and if deemed necessary by the Inspection Department having jurisdiction, must be enclosed in an approved case.

From the nature of the question the decision as to what is an approved case must be left to the Inspection Department having jurisdiction to determine in each instance.

g. Must, when combined with ceiling fans, be hung from insulated hooks, or else there must be an insulator interposed between the motor and its support.

h. Must each be provided with a name plate, giving the maker's name, the capacity in volts and amperes, and the normal speed in revolutions per minute.

29. Motor starting boxes with automatic release, to open the circuit if the motor is overloaded or if the current is cut off for any reason, such as the opening of the main switch, have come into very general use. They are a very great protection to the motors, and are much more convenient than the old starting boxes. Automatic circuit-breakers can be installed to answer very nearly the same purpose.

The Underwriters' rules prohibit the operation of motors or lights from street-railway circuits, except in street cars, car barns, or railway power houses. The reason for this is that one side of a railway system is grounded to the rails, and the installation of motors or lights would always introduce more or less fire risk.

BELL WIRING.

30. Electric bells, burglar alarms, and electric gas-lighting appliances bring in another class of wiring with which the wireman has to deal. If these appliances are put in properly, they may be a great convenience; if not, they are continually getting out of order and may prove to be a regular nuisance. This class of work is often slighted and put up in a cheap manner, but it will pay in the end to have it put up carefully. The bells and annunciators which show from what point the bell was rung are operated by primary batteries, which are of low voltage, and no fire hazard is introduced if the bell wires are kept well separated and insulated from electric light and power wires.

THE ELECTRIC BELL.

31. The electric bell is a very simple piece of apparatus. In Fig. 5 is shown a type of skeleton bell, in which all the parts are visible. The battery wires are connected at the terminals *t*, *t'*, and the course of the current is as follows: From the terminal *t* to the adjustment screw *s*, which is tipped with platinum in order to prevent oxidation of the contact surface, through the spring *l* and the end *p* of the armature to the coils of the magnets *m*, *m'*, and out at the terminal *t'*. When no current is passing, the armature is held away from the poles of the electromagnets, as in the position shown, but as soon as a battery circuit is closed and a current sent through the coils, the magnets become energized and attract the armature *a*, which swings about the pivot *p*, causing the

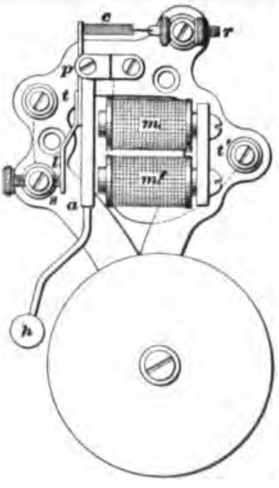


FIG. 5.

hammer *h* to strike the bell. This movement breaks the circuit between *s* and *l*, and the iron cores being thereby demagnetized, the spring *c* draws the armature away, when the spring *l* again touches the screw *s*, completing the circuit. As long, then, as the battery current is free to flow, this vibration of the armature and hammer will continue. The tension of the release spring *c* may be changed to suit the strength of the battery by means of the regulating screw *r*, which is provided with nuts for this purpose on each side of the supporting pillar. The bell mechanism is usually enclosed to prevent entrance of dust or insects, which may interfere with the working of the bell by lodging on the contact points, thereby preventing the current from passing through the magnets.

32. The bell just described is of the common vibrating class. When a bell is required to give a single stroke each time the circuit is closed, that is, for each pulsation of current, a slight difference in the connection of the ordinary bell is necessary. A wire is connected between the end of the magnet coil *m* and the terminal *t*, so that the circuit is simply from one terminal to the other through the coils. Hence, when a current passes through the coils, the armature is attracted and held, a single stroke being given to the bell; on interrupting the current, the armature is drawn back to its normal position by the spring *c*.

33. The **buzzer,** shown in Fig. 6, is used in places where an electric bell would be undesirable, as in small, quiet rooms or on desks, and is constructed on the same principle as the bell except that the armature does not carry a hammer. In the illustration, the cover *c* is removed, showing the magnet coils *m*, *m'* and the armature *a*. An adjusting screw *s* is provided to regulate the stroke of the armature and the consequent intensity of sound. The wires from the push button and battery are secured at *d* and *e*, and on closing the circuit, the rapid vibration of the armature causes a humming or buzzing sound, whence the name.

Buzzers are generally used for signaling between the dining room and kitchen, as a bell usually makes too much noise for this purpose.

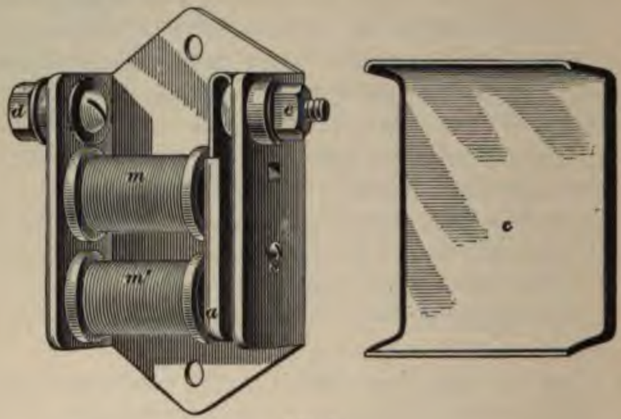


FIG. 6.

34. The circuit-closing devices used on bellwork usually take the form of a **push button.** These are made in all sorts of styles. The very cheap ones are seldom satisfactory. Bronze push buttons should be used where exposed to the weather. Fig. 7 shows the ordinary round push button. The wires enter through holes in the base and attach to springs *b* and *c*. The cover *d* screws on, and when *e* is pushed, *b* and *c* come together, thus completing the circuit.

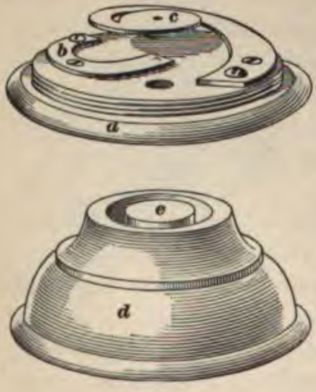


FIG. 7.

One cell of any good type of battery will ring a good bell over a short length of wire, but it is never advisable to rely upon less than 2 cells even on the smallest installations. When several cells are connected together to form a battery, the zinc of one must be joined to the carbon of the next and the free terminals at the ends of the row of cells connected to the line wires.

35. Electric bells can be had of all sizes, from mere tinklers up to the largest fire gongs. Very cheap bells should not be used. They require much battery power, and soon get out of order. Trouble is usually found first at the contact points or the armature pivot. Contact points should be tipped with platinum or silver; platinum being much the better material for this purpose, as it never corrodes or tarnishes, but it is more expensive than silver, which is much used.

36. In an ordinary dwelling there are usually not less than three electric bells, one located at a convenient point in the hall with a push button at the front door; one in the kitchen with a push at the back door, and one, a buzzer, located in the kitchen with a push in the dining-room floor. These bells may all be operated by the same battery. The battery should be placed in a cool place, but where it never is cold enough to freeze; preferably in the cellar, where the air is not so dry that the water in the cells evaporates rapidly. Cells should not be allowed to become dry. Water should be added from time to time so as to keep the level of the solution up to the proper height, which is usually marked on the glass jar.

BATTERIES.

37. Many different types of cell are manufactured that are suitable for bellwork. Most of those used for bellwork are of the **open-circuit** type. They are intended to furnish current for short intervals only and will run down if used continuously. Crosses between the wires or grounds will often cause the cells to run down rapidly. Most of these cells will recover to a certain extent if allowed to stand for a while on open circuit, but they should never be allowed to become short-circuited if it is possible to avoid it.

The cells in ordinary use on bellwork have electrodes of zinc and carbon and contain a solution of sal ammoniac (ammonium chloride). Sometimes they also contain a "depolarizing" agent, such as manganese dioxide. The effectiveness of a carbon-zinc cell depends largely on the materials of which the carbon element is made and the skill used in its manufacture. Burning the carbons too much or too little in the process of manufacture makes them inferior. Some manufacturers make inferior carbons and then treat them with sulphuric acid, to make them operate with vigor when first installed. Such cells soon become polarized, and in the course of a few weeks or months are very inferior, not because of the acid so much as because of the poor quality of the carbon.

Where batteries are to stand considerable use, cells with depolarizing agents must be employed. Where batteries are worked very severely, being in almost constant use, more expensive cells must be employed. Where there are facilities for charging, storage batteries are very convenient for this kind of work. Dry cells are used to a considerable extent in connection with light bellwork and portable electrical devices. There are many varieties of electric cells, some of which are very useful and economical, but they all require more or less care. The study of the merits and demerits of these devices is not within the scope of this Course.

38. The Leclanché Cell.—Fig. 8 shows a type of cell that has been largely used for bellwork. It consists of a porous cup *P*, containing the carbon electrode *C*, to which a binding post *B* is attached; also a zinc rod *Z*, both being enclosed in a glass jar with a contracted top. The zinc rod is provided with a binding screw B_1, which serves as the negative terminal of the cell, *B* being the positive terminal. Before the battery will furnish current, the jar must be filled to the point shown in the cut with a saturated solution of sal ammoniac, and in connecting up, the zinc of one jar is joined by a short piece of wire to the carbon of the next. This gives the series grouping, which is usually required in bellwork. When, after considerable use, the current from the cells becomes feeble, it will be necessary to replace the liquid, but it frequently happens that the power may be restored by the addition of a little water to make up for evaporation. The zinc will in course of time be consumed, and must be replaced, and the sal ammoniac may also be renewed at the same time, although it should last longer than a single zinc rod of the usual size (⅜ inch diameter). After five or six rods have been used, the material inside the porous cup will no longer act effectively, and this means practically a new carbon and cup, since they may be procured very cheaply. In the case of renewal of a large number of cups, they may be returned to the manufacturer and recharged by him.

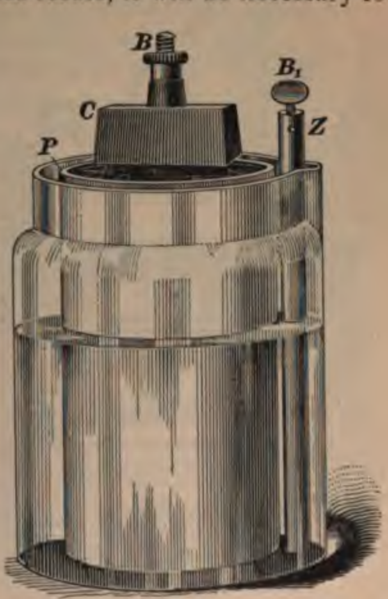


FIG. 8.

39. Carbon cylinder cells are a modified form of the Leclanché. Sal ammoniac is used as the exciting fluid, or electrolyte, but the porous cup is omitted. In its place a carbon cylinder is used that presents a large surface, and hence makes the cell have a low internal resistance.

ANNUNCIATORS.

40. When a number of push buttons are installed, it is necessary to have an indicating arrangement to show from which button the bell is rung. The instrument used is called an **annunciator.** One ordinary house style is shown in Fig. 9. On the face are rows of small windows, before one of which an indicator appears when the bell rings, showing from which room the signal has been sent. A handle *h* at the side is intended to be used to restore the indicators to their normal position when the call is answered. A view of the indicator itself is given in Fig. 10. A hinged arm *a* carries a card bearing the name or number of the room to which the drop is connected, and is held up in the position shown by a counterbalanced trip *t* in front of an electromagnet *m*. As soon as the current passes through the electromagnet, the trip is attracted and the indicator falls, being then visible from the outside through one of the openings in the front.

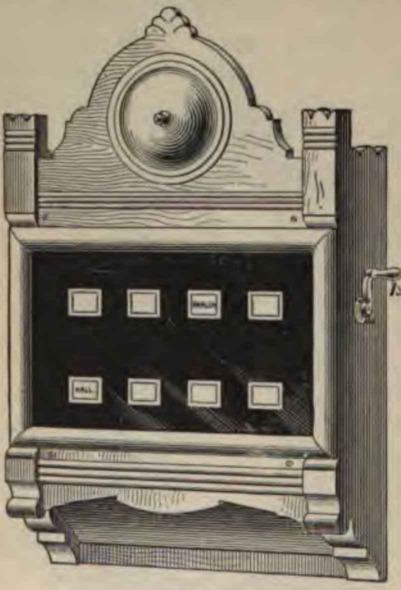


FIG. 9.

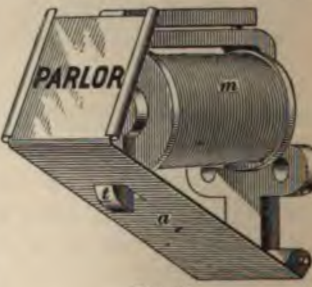


FIG. 10.

41. The **needle annunciator,** Fig. 11, is a style much used in hotels and for elevators. The current on passing through the electromagnet of an indicator attracts a pivoted, iron armature carrying a pointer *P* on the outside dial, causing it to set in an oblique position, in which it is held by a catch until released by pressing the knob *k* below the case. Annunciators may be obtained in almost any desired finish and for any number of drops. One type that has lately become very popular is the **self-restoring annunciator.** In the ordinary instrument the drops must always be put back after a call comes in. Sometimes this is not done, and consequently one is at a loss to know, when several are down, which button has been pushed. Self-restoring annunciators are constructed so that when a button is pushed, its corresponding drop falls and remains down until the next call is sent in. This operates a magnet that moves the restoring device and resets the first drop. Self-restoring annunciators are somewhat more liable to get out of order than the simple kind and some of them require more battery power. They are, however, a great convenience, and are rapidly finding favor. They are wired up to the buttons in the same way as an ordinary annunciator, as the restoring device is wholly within the annunciator itself.

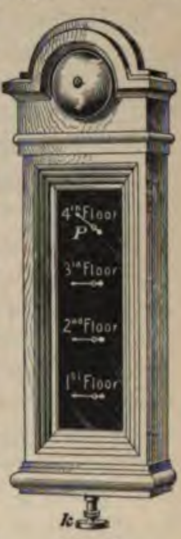


FIG. 11.

RUNNING BELL WIRE.

42. There are no regulations governing the insulation used on bell wire. That generally used is known as *annunciator wire* and is usually No. 16 or No. 18 B. & S. copper-covered, with two wrappings of cotton treated with paraffin. This wire is cheap, but it is not moisture-proof, and the insulation does not adhere very firmly to the wire. However, it will work satisfactorily if it is carefully put up and is run in a dry place. For really good work, *weather-proof office wire* should be used. The insulation on this wire is heavier than on the annunciator wire and adheres firmly; it is also damp-proof. If it is necessary to run bell wires where they will be exposed to considerable moisture, the best plan is to use rubber-covered wire.

The size of wire used is generally No. 16 or No. 18 B. & S

It will pay to use nothing smaller than No. 16, because the cost is very little more and the line resistance is thereby reduced. Also the batteries work to better advantage and the line is mechanically stronger. For the main-battery wire in large installations, No. 14 may be used to advantage.

Bell wires are often stapled to woodwork, especially when bells are installed in old houses. If any stapling is done, care should be exercised not to drive the staples so hard that they cut through the insulation and break the wire. Do not fasten two wires down under the same bare staple. Special staples, using a small saddle of leather between the wire and the top of the staple, are made for this work. When bell wires are run in new buildings, they may usually be run through holes in the beams, and they should be grouped together as much as possible. By doing this, the wires are run in an orderly manner and very little stapling is needed.

In the best class of work, bell wires are sometimes run in conduits, but no matter how they are run, all circuits should be carefully tested out after they are put up to make sure that there are no grounds, breaks, or crosses. See that all bell wires are kept well away from electric-light wires.

BELL AND ANNUNCIATOR CIRCUITS.

43. Simple Bell Circuit.—A simple bell circuit is shown in Fig. 12. A battery of two Leclanché cells *c*, *c* connected in series furnishes current to the bell *b*, located at any part of the house, and the push button *p* is placed at any convenient point.

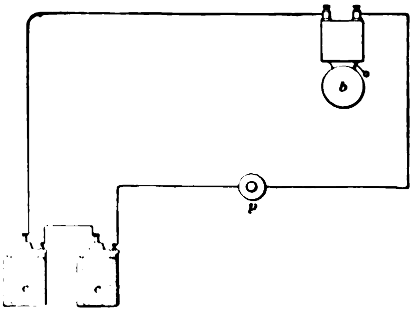


FIG. 12

44. Two Bells Operated From One Point.—It is frequently necessary to ring two or more bells from one push button.

This may be accomplished by one of two methods. One is to connect the bells in multiple arc across the leads, as in Fig. 13, so that each one is independent of the others, the bells *a*, *b* being on separate branches. The battery *B* is represented in this diagram in the manner generally adopted, the fine line indicating the carbon of the cell and the heavy line the zinc. The other method, making use of a series arrangement, is shown in Fig. 14. This is often preferred to the first method, because there is usually a saving of wire in its use, but it is necessary to change all but one of the bells to single stroke. The reason for this is that, unless the bells were exactly similar in their adjustment, the period of vibration, or rate of swing, of the armatures would be different, and the interference would prevent satisfactory ringing of the bells. If, however, one bell is free to vibrate and the rest are all changed to single stroke, very little adjustment of each one will be required to produce a strong clear ring.

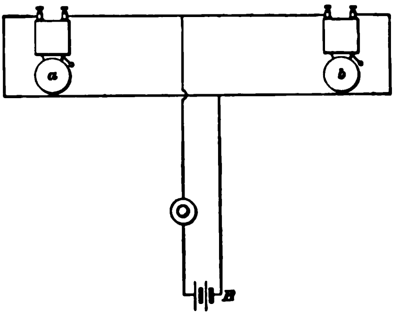


FIG. 13.

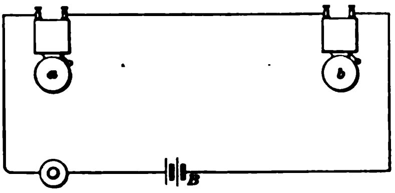


FIG. 14.

45. One Bell Operated From Two Points.—When it is desired to ring a bell from two different places, a simple series circuit cannot be used, because there would be a break at each

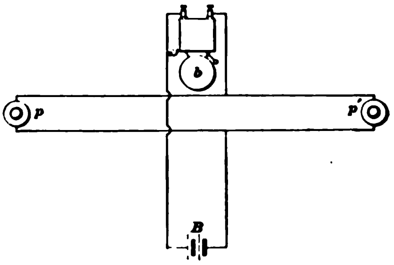


FIG. 15.

push button and a current would not flow unless both buttons were pressed at once. The second button must then be in parallel to the first, as in Fig. 15, so that whichever button p or p' is pressed, the circuit through the bell b and battery B is completed.

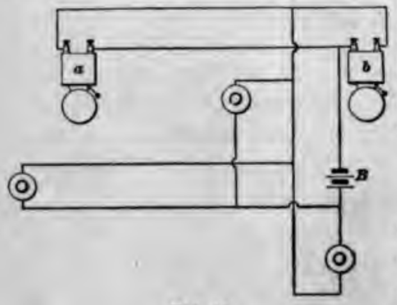


FIG. 16.

46. Figs. 16 and 17 show two arrangements of wiring for ringing two bells simultaneously from three different points. The bells a, b are connected in parallel in Fig. 16, but they may be put in series, if desired, as in Fig. 17, provided one of them is changed to single stroke. In the case of an actual installation, it might be necessary to run the wires in some other manner than as here laid out, depending on the construction of the building; but, from the directions already given, it should be an easy matter to devise the best arrangement. The choice between series and parallel connection of the bells will depend on which is more economical in copper for the line wires.

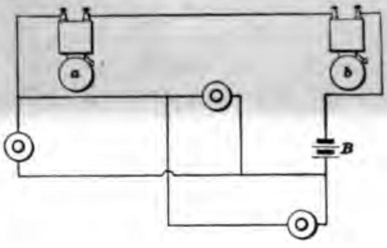


FIG. 17.

Placing the bells in multiple requires a larger volume of current to be supplied than when they are in series, because the total current subdivides among all the bells. This calls for a large battery and large wires. When the branch circuit containing one bell is very much longer, and hence of higher resistance than the branch containing another bell, the current will not divide equally between the two bells, and hence the parallel arrangement may not be satisfactory in such cases. Placing the bells in series requires an additional cell or two, but no larger wire is required.

47. Wiring for Three Bells and Three Push Buttons.—Fig. 18 shows a plan of wiring that is often used for the bell system in a small dwelling where no annunciator is used.

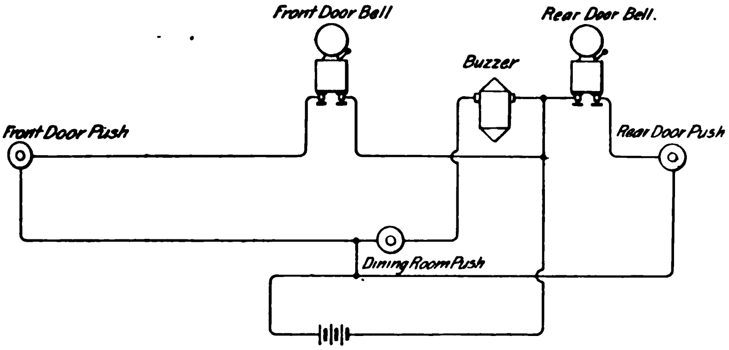


FIG. 18.

48. Wiring for Simple Annunciator.—A wiring diagram for a simple annunciator system is shown in Fig. 19. The pushes *1*, *2*, *3*, etc. are located at convenient points in the various rooms, one terminal being connected to the battery wire *b* and the other to the leading wire *l* communicating with the annunciator drop corresponding to that room. The battery wire is run from one pole of the battery direct to one side of each of the pushes. The other side of each push is then connected to its drop on the annunciator. A battery of three or four Leclanché cells is placed at *B* in any convenient location, but should not be set in a dark or inaccessible spot or be exposed to frost.

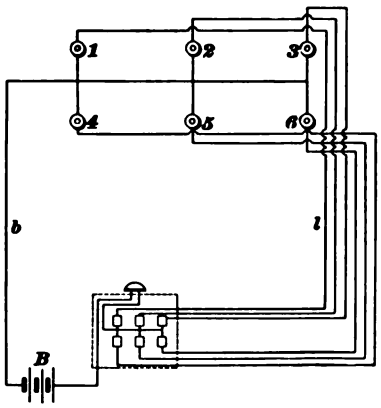


FIG. 19.

49. Wiring for Return-Call Annunciator.—In Fig. 20 is illustrated a return-call system requiring one battery wire *p h b*, one return wire *r*, and for each room one leading wire l_1, l_2, etc. The annunciator board is divided into two parts, the upper part having the numbered drops and the lower the return-call pushes. Each room is provided with a double-contact push, such as that shown in Fig. 21. The tongue *t* makes connection normally with the upper contact *c*, but when pressure is put on the button *k*, the tongue is forced against the lower contact *c'*. The return-call pushes on the lower board of the annunciator are of the same description. In Fig. 20 all these pushes are shown diagrammatically, for convenience in tracing out the circuits. The closure of the circuit in any room, as, for example, No. *4*, releases the corresponding drop and rings the office bell *f*. The path of the current is then from the push *4* through *c–d–e–f–g–B–h–o*, and back to the lower contact of the push button. On the return signal being made from the office, the annunciator-bell circuit is broken at *d*, and, the push button in the room being released, a new circuit is formed through *k*, as follows: from the battery *B* through *g–m–r–n–o–a–c–k–p* to the battery, the room bell being in this circuit.

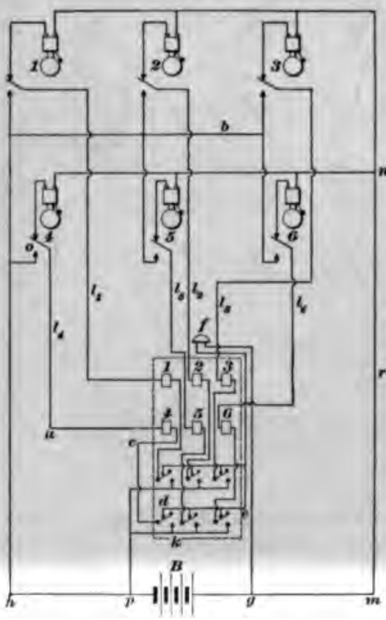


FIG. 20.

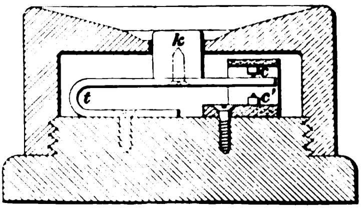


FIG. 21.

50. In installing annunciator systems, it is usual to run the battery wire, which is No. 14 or 16 annunciator wire, through the building at some central portion. If there are many rooms, it will be advisable to splice on a length of No. 18 wire to extend from the push in each room to the battery wire. The connection from the other side of the push button to the annunciator, that is, the leading wire, should be No. 18. For the return-call system, a battery of four or five Leclanché cells is required.

All wires used in annunciator service should have distinguishing colors to prevent confusion. The battery wire may be blue, the return wire red, and the leading wires white. This arrangement will greatly simplify the connections and reduce the liability of mistake.

51. Wiring for Elevator Annunciator.—The wiring for an elevator annunciator does not differ greatly from that of a simple annunciator; in fact, the scheme of connections is essentially the same. A battery wire *b*, Fig. 22, is run up the shaft and connected to each push button on the different floors. The return wires from each button are then carried to a point *a* at the middle of the shaft, where they should terminate in a small connection board, so that they may be readily disconnected from the wires in the cable running to the cage *c*. The wires running from the connection board to the cage are in the form of a flexible cable, which is made especially for this kind of work. This cable contains one more wire than there are push buttons, because it has to provide for the return wire *r*.

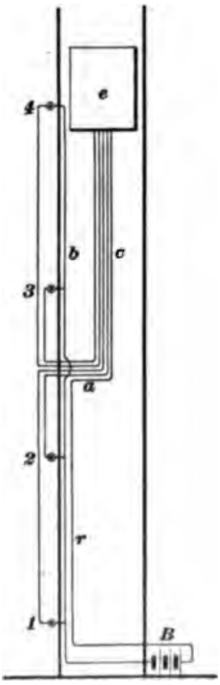


FIG. 22.

SPECIAL APPLIANCES.

52. The Automatic Drop.—For special alarm purposes, it is sometimes desirable that the bell should continue to ring after the push is released. This is accomplished by the use of an **automatic drop**, which closes an extra, or shunt, circuit as soon as a current passes along the main circuit.

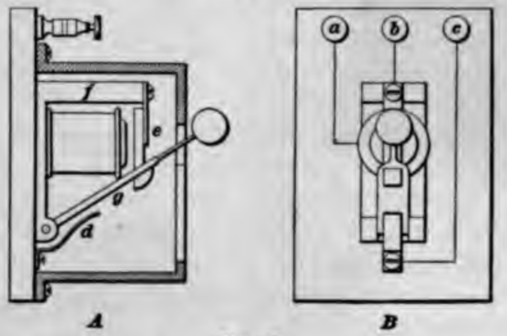


FIG. 23.

Fig. 23 shows two views of an automatic drop, *A* being a side elevation and *B* a front view with the cover removed. There are three terminals on the baseboard; those marked *a* and *b* are connected to the ends of the magnet coil, the end at *b* being also connected to the frame *f*; terminal *c* makes connection to the spring contact *d*, which is insulated from the frame and all other wires. The bell circuit is closed first through *a*–*b* by means of the push button; the armature *e* is at once attracted, thereby releasing the rod piece *g*, which falls by gravity and makes contact with the spring *d*, establishing a circuit between *b* and *c*, which short-circuits the push button and magnet coil of the drop.

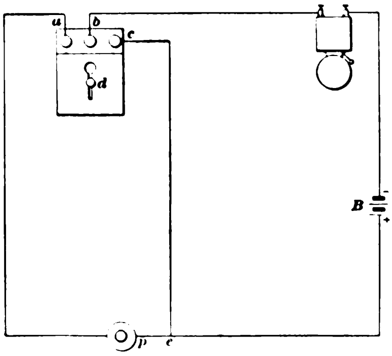


FIG. 24.

53. The connections for the automatic drop are shown in Fig. 24. Th circuit obtained, on pressing the push button *p*, is from the positive pole of the battery *B* through the push to the terminal *a* of the drop, through the magnet coils to *b*, and then through the bell to the negative pole of the battery. As soon as *d* falls, the magnet coils are cut out, the current being diverted at *c*, and passes by way of the new contact from *c* to *b*, and thence through the bell and back to the battery.

54. Two-Point Switch.—When two bells are arranged to ring from one push button, it is sometimes desirable to cut one of them out during some part of the day. For this purpose a small switch, Fig. 25, is used, by means of which one bell, when connected in series with the other, may be short-circuited. The wires are run to the back of the switch, one connection being to the lever arm at *a*, the other to the contact piece *b*.

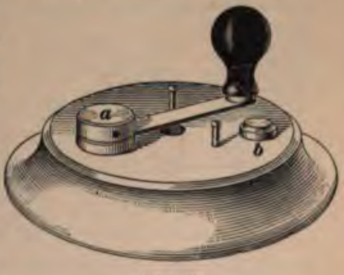


FIG. 25.

55. Door-Openers.—In apartment houses, banks, and other places, it is often convenient to have the latch on a door arranged so that the door may be unlocked from some distant point. For this purpose **door-openers** are used. These are made in a number of different styles, the mechanism differing with the different makes. In all of them, however, the unlocking is effected by means of an electromagnet, which is connected to the push and battery in the same way as an ordinary bell.

56. Operating Bell From Lighting Circuit.—It is sometimes convenient to operate an electric bell from an incandescent lighting circuit. This may be done where direct current is used to operate the lamps, but if alternating current is used, an ordinary bell will work very poorly, if at all. Of course, it is necessary to use a resistance in connection with bell in order to limit the current. The amount of resist-e will depend on the kind of bell used, because some bells uire much more current than others. Incandescent lamps ke a cheap and convenient form of resistance. Fig. 26 (*a*) ows a bell *a* and push button *b* in series with 4 lamps *l* ross a 110-volt circuit. This is the simplest scheme of con-ection, but there is apt to be bad sparking at the contacts n the bell, because the voltage across the break rises to

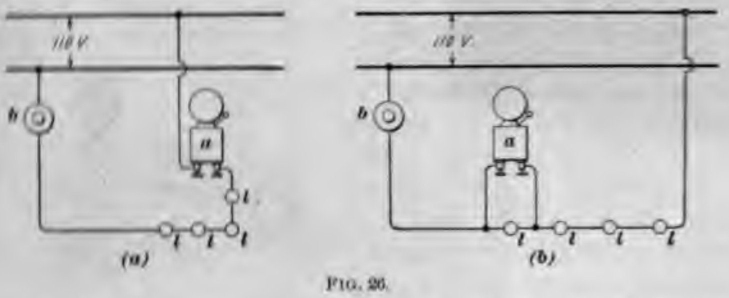


FIG. 26.

110 volts at the instant the circuit is broken. (*b*) shows the bell shunted across one of the lamps, in which case the voltage at the break would be much smaller. The operation of bells from lighting circuits is not to be recommended unless the bell wiring is done as carefully and with a view to as good insulation as the light wiring. Ordinary bell wiring put up with staples, etc. should *not* be connected to any source of pressure exceeding 10 volts, and it would be decidedly unsafe to connect it to a 110-volt circuit.

BURGLAR ALARMS.

57. Automatic switches may be placed on windows anc doors, in connection with alarm bells, to indicate whe entrance into a building is being forced. There are tw methods of installing these alarms: the open-circuit and t closed-circuit systems. In the **open-circuit system,** whi is the one usually employed, the connections are similar those of an ordinary electric-bell circuit, the automa circuit-closing device being substituted for the push button. A window spring used in this system is shown in Fig. 27. This is let into the window frame, the cam *c* alone projecting; when the window is raised, the cam is pressed in, revolving about the pin *p*, and makes contact with the spring *s*, which is insulated from the plate by a washer at the lower end and is normally prevented from touching the cam by an insulating wheel *w*. The wires from the bell and battery are connected to the plate and spring, respectively. The annunciator used is much the same as that employed for bellwork, but additional, convenient attachments are usually placed on it, such as a device to keep the bell ringing until the annunciator is reset, a clock to connect and disconnect the system at certain hours, etc. The annunciator is usually equipped with a small button over each drop, which when pushed will complete the circuit and cause the drop to fall if there happens to be any door or window open. These are very useful for testing out to see if everything is closed. All these appliances belong to the annunciator itself and do not affect the general plan of wiring, which is carried out in the same way as for bell wiring.

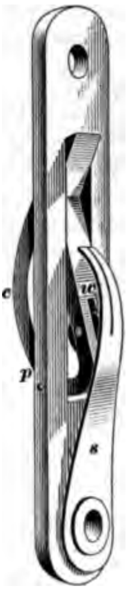


FIG. 27.

58. In the **closed-circuit system,** automatic switches of various styles are used, but the contacts are held together

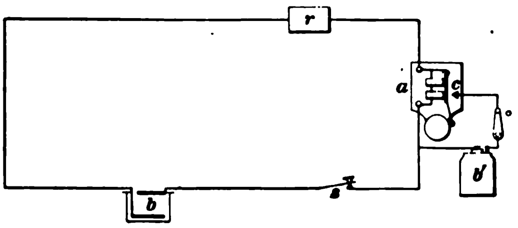


FIG. 28.

when the alarm is set, and a movement of the window or door breaks this contact. Two batteries are required for this system, one being a closed-circuit gravity battery indicated at *b* in Fig. 28, connected in series with a resistance *r* of about 200 ohms, the magnet coils of the bell *a*, and the alarm switch *s*. The armature of the bell is thus held away from the back contact *c*. The open-circuit Leclanché battery *b'* is connected to this contact and to the far terminal of the magnet coils; this circuit is therefore normally open, but as soon as the main circuit is opened by moving the alarm switch, the spring on the armature of the bell presses it against the back contact, thereby closing the local circuit through the bell.

59. Fig. 29 shows a **crowfoot** or **gravity** cell, the type generally used when a small current has to be furnished continually. A sheet-copper electrode is placed at the bottom of the jar along with crystals of copper sulphate. A solution of zinc sulphate covers the zinc, and on account of the copper-sulphate solution being more dense than the other, the two solutions do not mix, hence the name gravity battery. The top solution should be drawn off from time to time and water added. If the dividing line between the solutions gets up as high as the zinc, a dark deposit will be formed on the zinc and the battery will become inoperative. This upward diffusion of the copper sulphate will occur if the cell is left standing

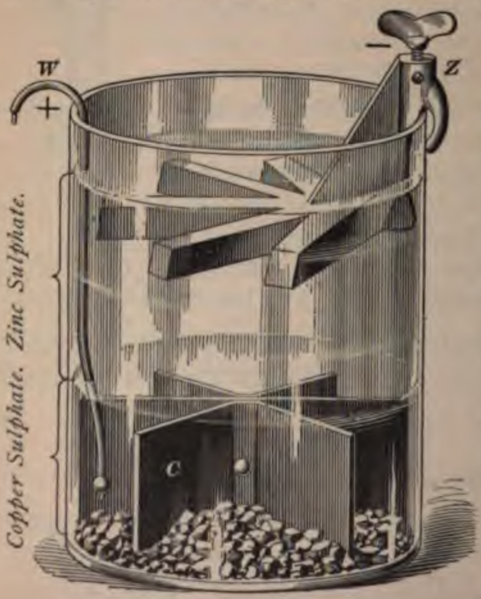


FIG. 29.

on open circuit. These cells will deliver a small, steady current, but their output is not large and they are rather expensive to maintain. The closed-circuit burglar-alarm system is little used in ordinary work in connection with dwellings.

It is usual when connecting up burglar-alarm annunciators to group the windows or doors; i. e., the contacts on several doors or windows are connected in parallel and attached to one drop. To provide a drop for each door and window would require too large an annunciator and would cost too much for the ordinary run of work.

ELECTRIC GAS LIGHTING.

BURNERS FOR PARALLEL SYSTEM.

60. In the application of electricity to gas lighting, a spark is caused to pass between two conductors, placed near the burner, at the same time that the gas is turned on. In the **parallel system** of lighting, each burner is independent of all the others, having direct connection between the battery wire and ground. Three different styles of burner are used: the *pendant*, the *ratchet*, and the *automatic* burner.

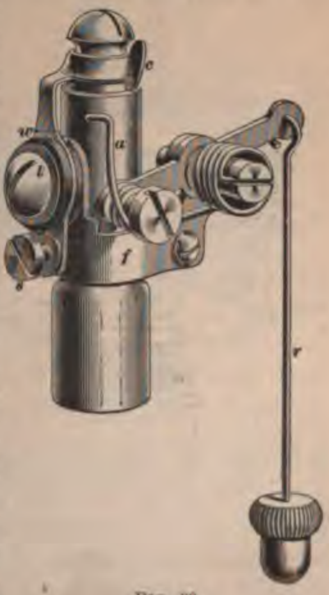


FIG. 30.

61. The **pendant burner** is shown in Fig. 30. A well-insulated wire is brought to the burner and secured under the head of the screw *s*, thereby making connection to the stationary contact piece *c*, which is fastened by a screw *t* to the frame *f* and insulated from it by washers *w*. On pulling the pendant *r* downwards, the spring *a* soft-iron wire and is wound with 5 or 6 layers of No. 18 magnet wire. The coil *k* is connected in series with the cells *c*, as indicated in Fig. 33. The battery should have at least six cells for satisfactory service. One end of the coil is connected to the gas pipe *p*. When the pendant is pulled, the tip makes contact and a current is established through the circuit. When the circuit is broken, the self-induction of coil *k* causes a bright spark at the break.

65. Wires for this purpose are usually run on the outside of the gas fixtures, but they may be concealed if there is sufficient room between the fixture shells and the gas pipe. It is advisable to use wire provided with good insulation for this kind of work, for the wires are particularly likely to become grounded upon the fixtures to which they are fastened. Where fixtures are wired on the outside, the wires should be painted or made with the proper colored insulation, so as not to show; but they must not be painted with bronze or metallic paint, which would penetrate the insulation and cause grounds, unless rubber-covered wire were used.

66. To make the location of grounds easy, it is advisable to run separate wires from a distributing point near the battery to each fixture or group of fixtures. The wires can be connected together at that point by means of a connecting board, at which any fixture can be disconnected. This makes the location and removal of grounds an easy matter. Fig. 34 shows the general arrangement of a system using both plain pendant and automatic burners. The distributing board is shown at *D*. The automatic burner is provided with a double push button *c*. When the dark button is pressed, the light is extinguished; when the light button is pushed, the gas is turned on and lighted.

In the above diagrams the gas pipe has been used as part of the circuit. This is done where the fixtures use gas only. Where electric light is used on the fixtures, the gas pipe must not be used as part of the circuit. The connections are, however, essentially the same. All that is necessary is

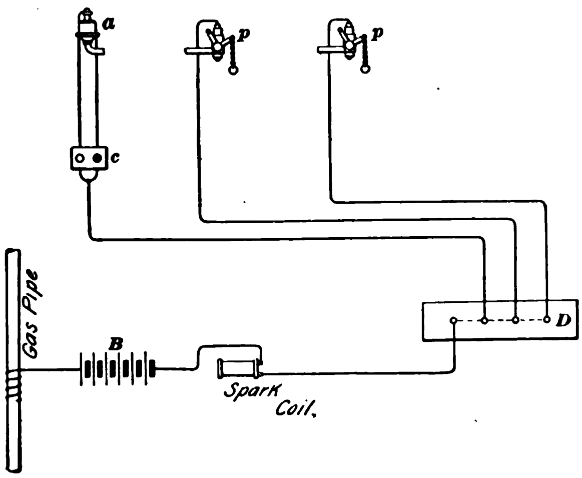


FIG. 34.

to use an additional wire instead of the pipe. The following Underwriters' rules relate to gas-lighting wiring in connection with electric-light fixtures.

Electric Gas Lighting.—

> Where electric gas lighting is to be used on the same fixture with the electric light:
>
> *a.* No part of the gas piping or fixture shall be in electric connection with the gas-lighting circuit.
>
> *b.* The wires used with the fixtures must have a non-inflammable insulation, or, where concealed between the pipe and shell of the fixture, the insulation must be such as required for fixture wiring for the electric light.
>
> *c.* The whole installation must test free from "grounds."
>
> *d.* The two installations must test perfectly free from connection with each other.

67. Since the battery is momentarily short-circuited every time a spark is obtained, it would soon run down if the contacts on the burner were to remain permanently touching. To give notice of this, a **relay** (Fig. 35) may be used in series with the battery, the current entering at *b* and passing out at *c*, after circulating around the coil. The magnetic circuit is completed by an armature *a*, which is held back against a stop by the weight *w* when no current is passing. If a short circuit occurs, the armature is attracted, and the spring *d* is pressed against the platinum-tipped screw *s*, completing a local circuit by means of the wires *e*, *f* through a vibrating bell and one-cell battery. The current used in lighting the gas at a burner is of such short duration that the bell is not rung. A modification of this arrangement is to provide an armature on the spark coil itself, which shall close a local alarm circuit when the battery is short-circuited.

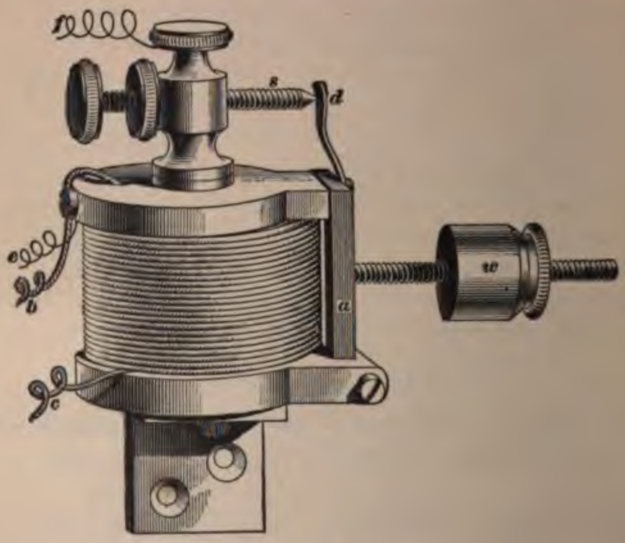


FIG. 35.

APPARATUS FOR MULTIPLE-LIGHTING SYSTEM.

68. The **multiple,** or **flash, system** of gas lighting is used in large halls where many lights are installed in groups. A fixed spark gap is used at each burner, both of the points being insulated from each other and from the gas pipe, except the last point of a series, which is grounded. The style of burner used is shown in Fig. 36, in which *a* and *b* are the points of the spark gap. To complete the connection between consecutive burners, a fine, bare copper wire, about No. 26 gauge, is stretched across, being secured through the small holes at the lower ends of the strips *a*, *b*. The body of the burner is made of some insulating substance, and a flange of mica *m* is added to give further protection. Since one circuit may consist of a large number of burners, it will be seen that the E. M. F. must be very high to force a current across so much air space, and to insure success, the wiring must be installed with the greatest precaution. The wire should nowhere be nearer to the gas pipe than 1¼ inches; if, however, it is necessary to approach more closely, the wire should be enclosed in glass tubing.

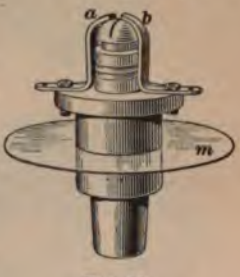


FIG. 36.

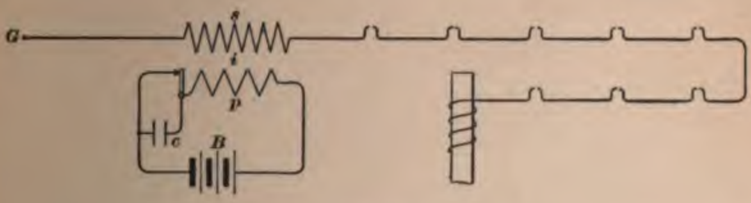


FIG. 37.

The apparatus required for this system of gas lighting consists of an induction coil *i*, Fig. 37, operated by a battery *B* and used with a condenser *c* across the spark gap of the primary *p*. The condenser cuts down the spark at the circuit-breaker, for this spark would be very destructive in the case of a large coil. The fine-wire secondary *s* is grounded at *G*, and the other terminal is connected to the line wire passing to the burners.

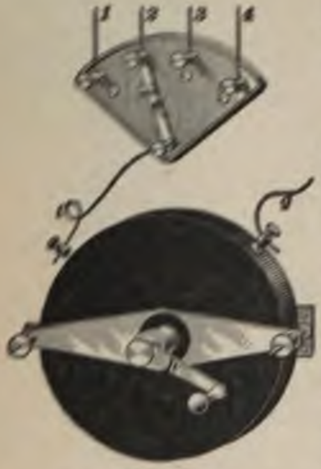


FIG. 38.

69. Frictional machines are also used in the multiple-lighting system. These generate static electricity, and in many cases are more reliable than induction coils, as there is no battery to get out of order. One form of this machine is shown in Fig. 38. One of the terminals *l* is to be connected to the switch handle *s* and the other *g* to ground. The machine is rotated by means of the handle *h*, and the switch is moved from one contact to the next, lighting the gas on each circuit *1*, *2*, *3*, *4* in rapid succession.

A SERIES

OF

QUESTIONS AND EXAMPLES

RELATING TO THE SUBJECTS
TREATED OF IN THIS VOLUME.

It will be noticed that the Examination Questions that follow have been divided into sections, which have been given the same numbers as the Instruction Papers to which they refer. No attempt should be made to answer any of the questions or to solve any of the examples until that portion of the text having the same section number as the section in which the questions or examples occur has been carefully studied.

ELECTRIC LIGHTING.

(PART 1.)

EXAMINATION QUESTIONS.

(1) Explain the action of a frequency changer.

(2) (*a*) Make a sketch showing how you would connect two large transformers on a single-phase system to feed three-wire secondary mains. (*b*) What are some of the advantages gained by supplying customers from secondary mains rather than from a number of small transformers?

(3) (*a*) How are incandescent lamps generally connected? (*b*) How are they sometimes connected on 220-volt and 500-volt power circuits?

(4) Describe briefly two methods of operating a three-wire system by means of a single 220-volt dynamo with auxiliary apparatus to take care of the balancing.

(5) (*a*) Name the principal parts of an incandescent lamp. (*b*) Of what is the filament made? (*c*) What material is used for the leading-in wires and why is this material used?

(6) (*a*) What three styles of lamp base are in most common use? (*b*) Which one of the three is used to the greatest extent?

(7) (*a*) What is the common unit used for expressing the brightness of a source of light? (*b*) To how many Hefner units is 1 standard candle equal?

(8) (*a*) What is a photometer? (*b*) Describe the Bunsen photometer.

(9) A photometer bar is divided into 500 equal parts and a standard lamp of 32 candlepower is placed at one end. The lamp to be measured is placed at the other end, and it is found that the screen becomes balanced when it is 350 divisions from the standard. What is the candlepower of the lamp under test? Ans. 5.88 c. p.

(10) (*a*) What is meant by the mean horizontal candlepower of an incandescent lamp? (*b*) How is the mean horizontal candlepower usually measured?

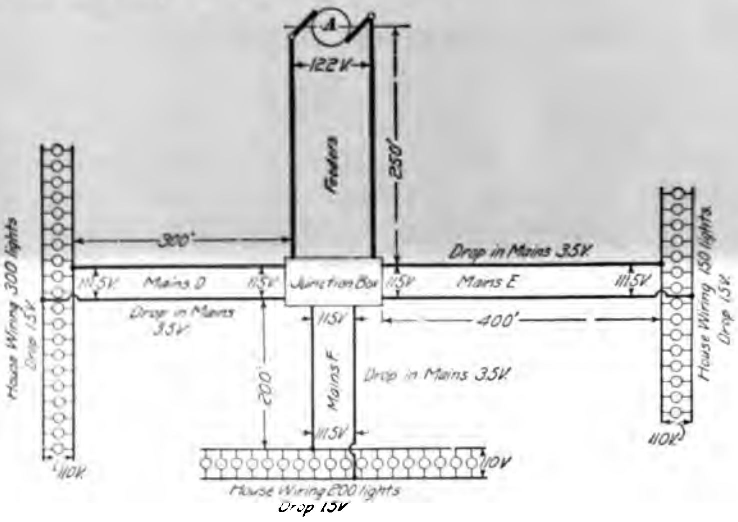


FIG. I.

(11) (*a*) At about what temperature is the filament of an incandescent lamp worked? (*b*) What is a fair value for the number of watts consumed per candlepower of an ordinary incandescent lamp?

(12) About how many 16-candlepower lamps can a 30-kilowatt dynamo run? Ans. 500.

(13) (*a*) What is the feeder-and-main system of distribution? (*b*) What are its advantages?

(14) Describe the Westinghouse method of operating incandescent lamps in series on constant-potential alternating-current systems. Illustrate by means of a sketch.

(15) Fig. I shows a two-wire 110-volt system, the number of lamps operated and the various distances being as shown. The total allowable drop from the dynamos to the lamps is not to exceed 12 volts. The drop in the house wiring is to be 1.5 volts, the drop in the mains 3.5 volts, and the balance of the drop is taken up in the feeders. Calculate the size of wire required for (*a*) the feeders; (*b*) the mains *D*; (*c*) the mains *E*; (*d*) the mains *F*.

Ans. (*a*) 250,714 cir. mils.
(*b*) 277,714 cir. mils.
(*c*) 185,143 cir. mils.
(*d*) 123,428 cir. mils.

(16) If a certain object is 10 feet from a source of light, how many times will the illumination on it be reduced if it is moved to a distance of 35 feet from the source?

(17) In making photometer tests on incandescent lamps, what three requirements should be fulfilled in order that the photometer screen may be set with a fair degree of accuracy?

(18) (*a*) Is the hot resistance of an incandescent lamp greater or less than the cold resistance? (*b*) What is the approximate hot resistance of an ordinary 16-candlepower 110-volt lamp?

(19) A 32-candlepower 220-volt lamp requires 4 watts per candlepower. What current will 160 of these lamps take on an ordinary two-wire system? Ans. 93.09 amperes.

(20) (*a*) What do you understand by mean spherical candlepower? (*b*) Are incandescent lamps usually rated by their mean spherical candlepower?

(21) The pressure on a long-distance electric-light feeder is to be raised 25 volts by means of a booster. The maximum current to be supplied to the feeder is 500 amperes. What must be the capacity of the booster in kilowatts?

Ans. 12.5 K. W.

(22) Draw a simple diagram showing how to connect a shunt-wound booster so as to raise the pressure on a two-wire circuit.

(23) Fig. II shows a three-wire system. The main feeders *C* run to a junction box *J*, from which current is distributed to the house wiring *F* by means of the mains *D*. Current is also supplied from *J* to the lamps *E* uniformly distributed as shown. The drop in the feeders *C* (i. e., the drop on one side of the circuit) is to be 5 per cent. of the lamp voltage, and that in the mains *D* 3 per cent. of the lamp voltage; the drop in mains *E* is to be 5 per cent. of the lamp voltage. The distances and number of lamps supplied are as shown on the figure. Calculate (*a*) the size of feeders *C*; (*b*) the size of mains *D*; (*c*) the size of mains *E*.

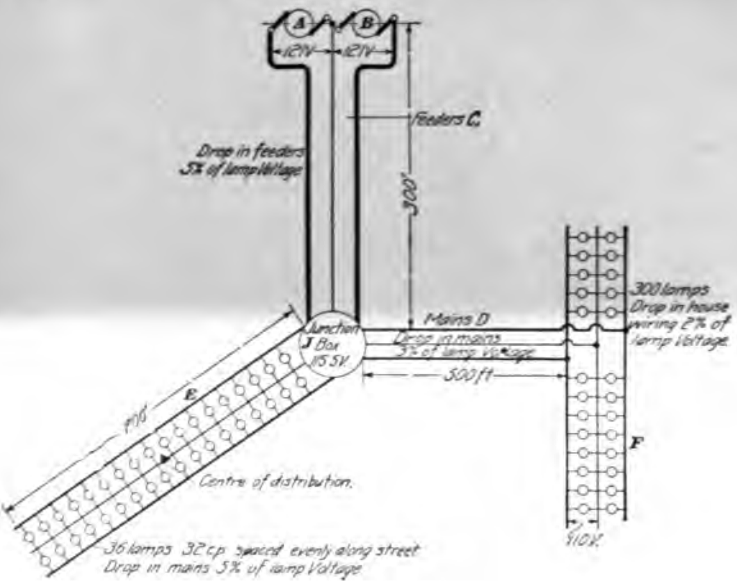

A
B
121V
121V
Feeders C
Drop in feeders 5% of lamp Voltage
300'
300 lamps
Drop in house wiring 2% of lamp Voltage
Mains D
Junction
J Box
115.5V
Drop in mains 3% of lamp Voltage
500 ft
E
F
Centre of distribution.
110V
36 lamps 32 c.p. spaced evenly along street
Drop in mains 5% of lamp Voltage

FIG. II.

Ans. { (*a*) 54,785 cir. mils.
(*b*) 122,727 cir. mils.
(*c*) 12,371 cir. mils.

(24) (*a*) What voltages are ordinarily used for operating incandescent lamps? (*b*) Give a table showing the approximate current required by some of the ordinary sizes of lamps.

(25) Three thousand 16-candlepower incandescent lamps are to be operated at a point 20,000 feet from the station The total loss in power is to be limited to 15 per cent., 10 per cent. of which is to be lost in the transmission line and 5 per cent. in the secondary wiring and transformers. The lamps require 3.5 watts per candlepower, and the voltage at the end of the line is to be 4,000. Find the size of the line wires required if the three-phase alternating-current system is used. Ans. 26,460 cir. mils; a No. 6 B. & S.

ELECTRIC LIGHTING.

(PART 2.)

EXAMINATION QUESTIONS.

(1) Name three of the principal ways in which storage batteries may be used to advantage in connection with lighting plants.

(2) Describe the action of the Stanley electrostatic ground detector.

(3) Give a list of the most important instruments and appliances used on a lighting switchboard.

(4) (*a*) For what are potential regulators used in lighting plants? (*b*) Describe the action of the Stillwell regulator.

(5) (*a*) How many field rheostats are generally used for each alternator on an alternating-current switchboard? (*b*) Where are these rheostats connected? (*c*) Is one field rheostat in series with the shunt field of the exciter sufficient to control the field excitation of an alternator?

(6) (*a*) Make a sketch showing how three lamps may be connected so as to indicate grounds on a three-wire system. (*b*) Describe the action of the lamps when a ground takes place on each of the lines.

(7) (*a*) For what are current transformers used? (*b*) Make a sketch showing how a current transformer would be connected.

(8) (*a*) Draw a diagram and describe the action of the two-lamp ground detector as used on ordinary two-wire direct-current circuits. (*b*) Why is a voltmeter to be preferred to lamps for the detection of grounds?

(9) (*a*) What style of switch is commonly used for low-pressure lighting switchboards? (*b*) Name some styles that are used on high-pressure alternating-current boards.

(10) What method is used for extinguishing the arc in the Garton lightning arrester?

(11) Make a sketch and describe the operation of the Westinghouse lamp ground detector as used on alternating-current circuits.

(12) Make a sketch showing how you would connect three Wurts 1,000-volt alternating-current arresters on a 3,000-volt line.

(13) Why are fuses being superseded by circuit-breakers on lighting switchboards?

(14) The bus-bars of a lighting switchboard have to carry 1,300 amperes. What should be the cross-section of the bars and give the dimensions of a bar that would answer?

Ans. About 1.3 sq. in., or 3 in wide by $\frac{7}{16}$ in. thick.

(15) What are pressure wires and for what purpose are they used?

(16) (*a*) What is an electrostatic voltmeter? (*b*) Does an electrostatic voltmeter require any current for its operation?

(17) (*a*) For what are potential transformers used? (*b*) Make a sketch showing how a potential transformer is connected.

(18) Explain the action of the Thomson inclined-coil type of alternating-current ammeter.

(19) What is an ammeter shunt and for what purpose is it used?

(20) (*a*) Is it necessary to equip each dynamo in a lighting station with an ammeter, and if so, why? (*b*) Is it necessary to equip each feeder with an ammeter?

(21) If the equalizer is connected to the positive side of a machine, in which side should the ammeter be connected? Give reason for your answer.

(22) (*a*) For what are pilot lamps used? (*b*) Should they be connected back of the main switch, i. e., between the main switch and the dynamo, and if so, why?

(23) How is the voltage of storage batteries used in lighting plants usually regulated?

(24) Draw a diagram showing how you would connect two compound-wound direct-current dynamos for parallel operation. The machines are to feed four circuits, each circuit being provided with a main switch and fuses. Each dynamo is to be provided with a main switch, circuit-breaker, ammeter, voltmeter plug, and pilot lamp. Also provide one voltmeter for connection to either dynamo.

(25) (*a*) For what are compensators used? (*b*) Explain the action of the Mershon compensator.

ELECTRIC LIGHTING.

(PART 3.)

EXAMINATION QUESTIONS.

(1) Describe the general construction of a horizontal type ratchet-feed searchlight lamp.

(2) Name some of the things that will cause burned-out shunt coils in series arc lamps.

(3) What are some of the main points of difference between an alternating-current constant-potential arc lamp and a direct-current constant-potential lamp?

(4) What should be the length of arc (*a*) for a 2,000-nominal candlepower series arc lamp? (*b*) for a 1,200-nominal candlepower lamp?

(5) What is likely to happen if constant-potential enclosed-arc lamps are operated on a higher voltage than that for which they are adjusted?

(6) (*a*) What kind of wire is generally used for arc-light lines? (*b*) Why is it advisable to have an arc-light line divided into loops that can be cut out by means of switches?

(7) (*a*) What is meant by a carbon-feed enclosed-arc lamp? (*b*) What are some of the advantages and disadvantages of a carbon feed?

(8) At what current and voltage are series enclosed-arc lamps commonly operated?

(9) (*a*) Why is a single coil in series with the arc incapable of regulating a series constant-current arc lamp? (*b*) Explain the action of a simple differential series arc lamp.

(10) Explain the action of a simple constant-potential lamp.

(11) Make diagrams showing how to connect arc lamps on (*a*) a direct-current constant-potential system, and (*b*) a constant-potential alternating-current system.

(12) (*a*) Why is it necessary to have an automatic cut-out in series arc lamps? (*b*) Why is it necessary to use a starting resistance in some styles of series arc lamp?

(13) How is the regulation of the Thomson-Houston series arc lamp brought about? Is this a differential lamp or is the feeding action controlled by the shunt coils alone?

(14) (*a*) How may the voltage at the arc on a General Electric constant-potential direct-current enclosed-arc lamp be adjusted? (*b*) How may the voltage be adjusted on the General Electric constant-potential alternating-current lamp?

(15) (*a*) What system of distribution is used almost exclusively for street lighting by means of arc lamps? (*b*) How are lamps switched out on such a circuit? (*c*) How must the voltage of the dynamo supplying such a circuit vary with the load? (*d*) Does the current vary, and if not, how is it kept constant?

(16) (*a*) What is a multicircuit arc machine? (*b*) Explain, by means of diagrams, the operation of two arc circuits from one machine and point out the advantages that are claimed for this method of operation.

(17) How many watts, approximately, do the following lamps consume: (*a*) a 2,000 nominal candlepower open-arc lamp? (*b*) a 1,200 nominal candlepower open arc?

(18) (*a*) Of what are ordinary arc-lamp carbons generally made? (*b*) Why do enclosed-arc lamps require a higher

grade of carbon than open-arc lamps? (*c*) What material is generally used for making enclosed-arc lamp carbons?

(19) (*a*) Make sketches showing at least three of the different methods of arranging the carbons for searchlights or other projection apparatus. (*b*) What is a Mangin mirror?

(20) (*a*) In direct-current lamps why should the upper carbon always be connected to the positive side of the line? (*b*) How would you find out whether a lamp were burning "upside down" or not?

(21) Does the direct-current enclosed arc form a well-defined crater like the direct-current open arc, and if not, what shape do the carbon points assume?

(22) What amount of current do open-arc direct-current series lamps usually take?

(23) (*a*) What is an enclosed arc? (*b*) How does the consumption of carbon in an enclosed arc compare with that in an open arc? (*c*) Give a description of the general arrangement of an enclosed arc.

(24) What are the characteristic features of a direct-current arc formed in open air between carbon points?

(25) (*a*) What is the approximate temperature of the electric arc? (*b*) Does an arc lamp using a large current produce a higher temperature at the arc than one using a small current? (*c*) What is the effect of increasing the current supplied to an electric arc?

(26) (*a*) In what direction does an open-arc direct-current lamp throw the greatest amount of light? (*b*) Why should reflectors be used with alternating-current arc lamps?

ELECTRIC LIGHTING.

(PART 4.)

EXAMINATION QUESTIONS.

(1) In Fig. 31, where would the plugs be inserted if machine *A* were connected to circuit *1'* and if machine *C* were running circuits *2'* and *3'* in series, machine *B* being shut down?

(2) Draw a diagram showing how you would connect a pair of Thomson lightning arresters on an arc-light circuit.

(3) How would you cut out an open-circuited coil on an arc machine having a closed-circuit ring armature?

(4) (*a*) Into what two classes may constant direct-current arc machines be divided? (*b*) Name some common makes of machine belonging to each of the classes.

(5) For what are transfer boards used in connection with arc-light switchboards?

(6) How would you locate a ground on an arc line by using a voltmeter?

(7) Give a general description of the method by which a Brush arc machine, equipped with an oil regulator, is made to regulate for constant current.

(8) Name some of the chief points of difference between the new and old styles of Brush arc dynamo.

(9) Name some of the precautions to be taken when connecting up circuits and dynamos on an arc plug switchboard.

(10) Why is it necessary to provide constant direct-current arc machines with a regulator ?

(11) On the board shown in Fig. 27, what would be the position of the plugs when machine *A* is operating circuit *1* alone, circuit *2* being dead, machine *B* operating circuits *3* and *4* in series, and machines *C* and *D* being shut down ?

(12) If alternating-curr es arc lamps are to be operated, is the alternati nt usually generated at constant potential or constant c ent ?

(13) What is the characteri feature of flashing at the brushes of an arc machine whe is caused by an open circuit in the shunt coils of one or re of the lamps ?

(14) Describe the principle l action of the Thomson constant-current transformer.

(15) About what should be the length of spark at the brushes on a T. H. machine when running under normal conditions ?

(16) Name some of the different methods that may be used for operating series arc lamps from constant-potential alternators.

(17) Give some of the defects that will lead to flashing on a T. H. arc machine.

(18) Describe the method of locating a break in an arc-light line by using a magneto-bell.

(19) (*a*) Why is it that in some cases two arc machines will not regulate well when run in series ? (*b*) How would you remedy matters ?

(20) Name some of the defects that will give rise to excessive sparking at the brushes of a T. H. arc dynamo.

(21) How would you right matters if the polarity of a series arc machine should become reversed ?

(22) For what purpose is a rheostat sometimes used in shunt with the field of a Thomson-Houston arc dynamo?

(23) Describe how you would locate a ground on an arc-light line by using a magneto-bell.

(24) If a coil on an armature is cut out on account of a short circuit in it, why should the coil be rewound before an attempt is made to operate the machine?

INTERIOR WIRING.

(PART 1.)

EXAMINATION QUESTIONS.

(1) In wiring a building for incandescent lamps, why is it important to have the drop in the various circuits limited to a small amount?

(2) (*a*) For what class of work is "slow-burning" weather-proof wire allowable? (*b*) How must this wire be supported?

(3) Where do the Underwriters' rules require automatic cut-outs (fuses or circuit-breakers) to be placed?

(4) (*a*) Why is it poor economy to burn incandescent lamps after they have become dim? (*b*) What is the effect of burning lamps above their normal voltage?

(5) How would you calculate the sizes of wire required for house wiring on the three-wire 110–220-volt system?

(6) Current is supplied to 120 16-candlepower 110-volt incandescent lamps on the three-phase system. What will be the current in each of the three wires if each lamp requires ½ ampere? Ans. 34.6 amperes.

(7) (*a*) About how many watts per candlepower does an ordinary incandescent lamp take? (*b*) A 32-candlepower

lamp requires 4 watts per candle and is operated in a 110-volt circuit; what current will the lamp take?

Ans. (*b*) 1.16 amperes.

(8) (*a*) For what are cut-outs used? (*b*) How are they usually constructed?

(9) If 500 16-candlepower lamps, each taking ½ ampere, are to be supplied by a 110-volt, four-wire, two-phase system, what will be the current in each line wire?

Ans. 125 amperes.

(10) What are the Underwriters' requirements relating to joints for wires used in connection with interior wiring?

(11) Point out some of the differences between open- and enclosed-arc lamps.

(12) A pair of feeders are to be installed in a factory building to carry current for 500 16-candlepower 110-volt lamps from the dynamo room to a center of distribution situated in another building; the total distance (one way) from the dynamo room to the center of distribution is 400 feet and the drop is to be limited to 5 volts. (*a*) What size wire will be required? (*b*) What size wire would be required if the carrying capacity alone were considered? Assume that weather-proof wire is used.

(13) Is the carrying capacity of rubber-covered wire as given by the Underwriters as large as that of weather-proof wire; if not, why?

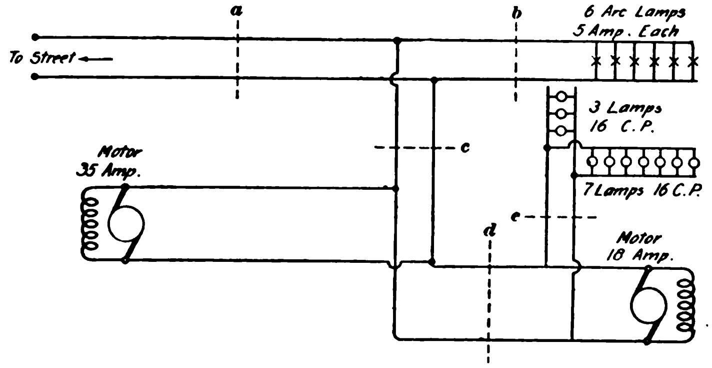
(14) Why is it not necessary to use large wires in order to avoid a drop when connecting constant-potential arc lamps?

(15) (*a*) Are the odd sizes of wire between Nos. 7 and 14 used for interior wiring, and if not, why? (*b*) What is a mil?

(16) In laying out the branch circuits, what determines the number of lamps to be allowed on any one circuit?

(17) Into what three general classes may fires caused by defective wiring be divided?

(18) The illustration shows a wiring plan of a network that supplies current to 110-volt lamps and motors as indicated. (*a*) Make a sketch and indicate the current flowing at *a*, *b*, *c*, *d*, and *e*. (*b*) Mark the sizes of wire necessary for the various parts of the system in accordance with the Underwriters' requirements, assuming that rubber-covered wire is used. (*c*) Show where main cut-outs or branch blocks would be required and the size of fuses to be used in order to protect the wire.



(19) What are the four most important things to be considered when installing a job of wiring?

(20) What is the effect of supplying a system designed for high voltage, say 104 volts, with low voltage, say 52 volts?

(21) When may single-pole switches be used in an interior wiring installation?

(22) (*a*) What is the smallest size of wire allowable for interior-wiring work outside of fixture wiring? (*b*) If no requirements must be met in regard to line drop, what determines the minimum sizes of wire to be used for a given installation?

(23) Into what two classes of circuits may house wiring usually be divided?

(24) (*a*) What is the principal advantage of the three-wire system? (*b*) What are some of the disadvantages of the three-wire system?

(25) Why should the two sides of a circuit always be run in the same conduit when alternating current is used?

(26) (*a*) Why should unprotected wires never be laid in plaster? (*b*) Why should electric-light wires never be fastened with staples?

INTERIOR WIRING.

(PART 2.)

EXAMINATION QUESTIONS.

(1) By the aid of Table I determine the size of wire that would be required for a line (2 wires) extending a distance of 120 feet and carrying 30 amperes with a drop not exceeding 3 volts. Ans. No. 6 B. & S.

(2) Find the area in circular mils of a round wire $\frac{1}{8}$ inch in diameter.

(3) After a building has been wired, what tests should be made?

(4) (*a*) What tests and observations does the Underwriters' inspector usually make? (*b*) When should concealed work be inspected by the Underwriters' inspector?

(5) What instrument is generally used in testing out connections, and also in testing for grounds and crosses?

(6) What size B. & S. copper wire should be used, allowing a drop of 2 volts, to supply a group of 80 110-volt 16-candlepower incandescent lamps at a distance (one way) of 200 feet? Each lamp requires $\frac{1}{2}$ ampere.

Ans. No. 1 B. & S.

(7) What is the diameter of a wire having a cross-sectional area of 10,816 circular mils? Ans. .104 in.

(8) What will be the current in the outside wires of an evenly balanced three-wire system supplying 60 lamps if

each lamp requires 52 watts? There is a drop of 2 volts in each outside wire, and the pressure between the outside wires at the center of distribution is 220 volts.

(9) Determine, by means of Table II, what size of wire would be required to transmit 30 amperes a distance of 120 feet (one way) with a line drop not exceeding 3 volts.
Ans. No. 6 B. & S.

(10) Calculate the size of wire necessary to supply 50 16-candlepower 110-volt lamps located in a group at a distance of 150 feet (one way) from the center of distribution, allowing a drop not to exceed 2 volts. Ans. No. 4 B. & S.

(11) In a building already wired, the drop in a certain feeder, extending a distance of 100 feet (one way), is excessive. The feeder, which consists of a No. 6 wire, carries 40 amperes. What size of wire should be connected in parallel with the No. 6 wire so as to reduce the drop to 2 volts?
Ans. No. 8 B. & S.

(12) What are the Underwriters' requirements (*a*) about supporting wires in damp places? (*b*) about the use of fuse blocks and rosettes in damp places?

(13) (*a*) Where may wooden molding for wires be used? (*b*) Where must it not be used?

(14) What two important conditions require additional precautions for ship wiring?

(15) (*a*) What appliances do the Underwriters require to be placed at a convenient point near where the wires enter a building in addition to the meter that is usually installed? (*b*) In what order should these appliances be placed?

(16) Make a sketch showing how a lamp or group of lamps may be controlled independently from two different points.

(17) Why should good metallic connections be made between all metal conduit pipes, outlet boxes, etc. and the ground?

(18) (*a*) Why is the flexible armored conduit not so good as the iron-covered conduit? (*b*) What kinds of conduits for concealed wiring are now approved by the Underwriters?

(19) What is the so-called loop system of wiring?

(20) What must be done when the size of wire is changed at a junction box?

(21) Where wires are brought through the wall to outlets or cut-outs, what precautions must be taken?

(22) How must wires be supported in concealed knob-and-tube work?

(23) Why will two wires (*a*) safely carry more current than one wire of equivalent cross-section and (*b*) give the same drop with the same total current?

(24) A wireman having at hand only some No. 14 wire desires to run a line a distance of 100 feet to supply 50 16-candlepower lamps requiring $\frac{1}{2}$ ampere each. How many No. 14 wires must be run in multiple in order to have a drop of about 3 volts?

Ans. Four No. 14 wires on each side of the circuit.

(25) In damp places (*a*) what kind of sockets must be used and (*b*) how should they be put up?

(26) (*a*) Where may single-pole switches be used? (*b*) Why are they used when possible in preference to double-pole switches?

(27) Why is it that No. 14 wire is generally used for lamp circuits in all ordinary dwelling houses?

(7) (*a*) The standard candle.

(*b*) 1 candle = 1.14 Hefner units. See Art. **19.**

(8) (*a*) A photometer is an instrument for comparing the candlepower of two sources of light and for measuring the candlepower of a source by comparing it with a standard whose candlepower is known. See Art. **20.**

(*b*) See Art. **24.**

(9) In this case, the distance of the standard from the screen is 350 divisions; hence, from formula **2,** $d_1 = 350$. The distance of the lamp from the screen is 500 — 350 = 150 $= d_2$; hence, the candlepower of the lamp test is, from formula **2,**

$$I = 32 \frac{150^2}{350^2} = 5.88 \text{ c. p.} \quad \text{Ans.}$$

(10) (*a*) The mean horizontal candlepower is the average of the light intensities given out by the lamp in all directions in the horizontal plane.

(*b*) It is usually determined by spinning the lamp about a vertical axis while the measurement is being made on the photometer. See Art. **28.**

(11) (*a*) From 1,250° to 1,350° C.

(*b*) About 3.33 watts per candlepower. See Arts. **32** and **33.**

(12) See Art. **36.** Applying the rule there given, we have

$$\text{Number of lamps} = \frac{30 \times 1,000}{60} = 500. \quad \text{Ans.}$$

(13) (*a*) A system in which the current is carried from the station to centers of distribution by means of feeders, which are not tapped at any intermediate point. From the distributing centers the current is supplied to the customers by means of distributing mains. See Art. **51.**

(*b*) Since lamps are not tapped off the feeders at intermediate points, a large drop may be allowed in the feeders

INTERIOR WIRING.

(PART 3.)

EXAMINATION QUESTIONS.

(1) Where it is necessary to install wires very cheaply for temporary or occasional use and for some special purpose, such as the illumination of the entire outside of a building, what are the important items to be kept in view and what are not so important ?

(2) What are considered as high-potential circuits ?

(3) On what does the ratio of the electromotive force at the terminals of the primary and secondary winding of a transformer depend ?

(4) Why cannot the same protective devices be used on constant-current as on constant-potential circuits ?

(5) What sort of switches must be used for constant-current systems ?

(6) (*a*) What is a self-restoring annunciator ? (*b*) What are its advantages ?

(7) To what class of work is the use of high-potential direct current almost exclusively confined in the United States ?

(8) Why do the Underwriters' rules prohibit the operation of motors or lights from street-railway circuits, except on street cars, or in car barns, or railway power houses ?

(9) State two particulars in which the wiring for constant-current arc lamps differs from that for other open work.

Also, if x_2 represents the degree of illumination in the second position, we have

$$x_2 = \frac{I}{35^2}.$$

Hence, we have

$$\frac{x_1}{x_2} = \frac{\frac{I}{100}}{\frac{I}{1,225}}.$$

$$\frac{x_1}{x_2} = \frac{1,225}{100}.$$

$$x_1 = 12.25\, x_2.$$

That is, the illumination at a distance of 10 feet is 12.25 times as great as that at 35 feet, or the illumination is reduced 12.25 times. See Art. **21.**

(17) See Art. **27.**

(18) (*a*) The hot resistance is much less than the cold resistance, because the resistance of carbon decreases as the temperature increases.

(*b*) About 220 ohms. See latter part of Art. **35.**

(19) See Art. **35.** The current required for each lamp will be equal to $\frac{32 \times 4}{220}$, and for 160 lamps it will be $\frac{32 \times 4 \times 160}{220} = 93.09$ amperes. Ans.

(20) (*a*) The candlepower that the lamp gives in the several directions reduced to what the candlepower would be if the light were given out uniformly in all directions. See Art. **30.**

(*b*) No; the mean horizontal candlepower is generally used.

(21) The booster must generate 25 volts and carry 500 amperes; hence, its capacity will be $25 \times 500 = 12,500$ watts, or 12.5 K. W. Ans.

(22) See Fig. 30. The sketch required will be somewhat similar to Fig. 30 except that a two-wire circuit should be shown, and, of course, only one booster will be required.

(23) In working the problem, we will consider the outside wires only and treat it as if it were a two-wire system. The current supplied the lamps E will be 1 ampere for each pair of lamps, because the lamps are 32 candlepower. The current supplied to branch E will, therefore, be 18 amperes. The current supplied to F will be $\frac{300}{4} = 75$ amperes, because these lamps are of 16 candlepower. The total current in the outside wires C will, therefore, be $75 + 18 = 93$ amperes.

(*a*) The drop in each of the feeders C is 5 per cent. of 110, or 5.5 volts, or the total drop for both sides is 11 volts, and by applying formula **5**, we have

$$A = \frac{21.6 \times 93 \times 300}{11} = 54{,}785 \text{ cir. mils. Ans.}$$

(*b*) The mains D carry 75 amperes and the drop on each side is 3 per cent., or 3.3 volts. The total drop in the outside wires is, therefore, 6.6 volts. The distance is 500 feet; hence,

$$A = \frac{21.6 \times 75 \times 500}{6.6} = 122{,}727 \text{ cir. mils. Ans.}$$

(*c*) In this case, the center of distribution is 350 feet from the junction box; hence, the distance to be used in the formula is 350 feet. The current is 18 amperes and the drop is 5 per cent. on each side, or 11 volts between the outside wires.

$$A = \frac{21.6 \times 18 \times 350}{11} = 12{,}371 \text{ cir. mils. Ans.}$$

It will be noticed that the branch feeders and mains D call for a larger wire than the main feeders C, although they carry less current. This is because of the longer length of D and the small drop allowed.

(24) See Arts. **41** and **42.**

Art. **85.** Total power supplied to lamps = $\times 3.5 = 168{,}000$ watts; power delivered at end of ine aries of transformers $= 168{,}000 + .05 \times 168{,}000$

ring to *Electric Transmission*, Part 1, and using la

$$\text{Circular mils} = \frac{D \times W}{P \times E_2^2} \times t,$$

we have t for this case $= 1{,}200$, $P = 10$, $D = 20{,}000$, $W = 176{,}400$, $E_2 = 4{,}000$; hence,

$$\text{Circular mils} = \frac{20{,}000 \times 176{,}400}{10 \times 4{,}000 \times 4{,}000} \times 1{,}200 = 26{,}460 \text{ cir. mils.}$$

Therefore, a No. 6 B. & S. wire should be used. Ans.

ELECTRIC LIGHTING.

(PART 2.)

(1) See Art. **57.**

(2) See Art. **33.**

(3) Switches, bus-bars, ammeters, voltmeters, circuit-breakers or fuses, rheostats, ground detectors, and lightning arresters. See Art. **1.**

(4) (*a*) To allow the voltage on the individual feeders running from the station to be varied.

(*b*) See Art. **54.**

(5) (*a*) Two rheostats are generally used.

(*b*) One is connected in series with the separately excited field of the alternator and the other in series with the shunt field of the exciter.

(*c*) Yes, if a very fine adjustment is not required and if a single exciter is not used to excite several alternators. See Art. **48.**

(6) (*a*) Make a sketch similar to Fig. 37.

(*b*) See Art. **29** for description.

(7) (*a*) Current transformers are used in connection with alternating-current ammeters when the current to be measured is very large or when it is not desirable to bring the high-pressure lines in contact with the instrument. The use of the transformer avoids the carrying of heavy currents through the ammeter and makes it much easier to construct and connect up.

These wires connect to the voltmeter in the station and the instruments indicate the voltage at the various centers of distribution. The voltmeter requires such a small current that there is practically no drop in the pressure wires. See Art. **16.**

(16) (*a*) One that depends for its action on the repulsion or attraction of bodies carrying static charges of electricity.

(*b*) No; at least the current is not appreciable because the capacity of these instruments is exceedingly small. See Art. **14.**

(17) (*a*) Potential transformers are used to step down the voltage so that an ordinary voltmeter may be used to indicate the line pressure. See Art. **12.**

(*b*) Make a sketch similar to Fig. 16.

(18) See Art. **11.**

(19) An ammeter shunt is a low resistance connected in shunt with the ammeter and in series with the circuit. The greater part of the current flows through the shunt, but a small fixed proportion also flows through the ammeter, and the ammeter scale can be marked to indicate the current in the main circuit. See Art. **10.**

(20) (*a*) Yes; because one must be able to tell at a glance just what load each machine is carrying.

(*b*) No, it is not absolutely necessary, but it is nearly always done in well equipped plants. See Art. **9.**

(21) The ammeter should be connected in the negative side, because part of the current delivered by the armature of the machine may flow through the equalizer, and an ammeter connected in the positive lead would not indicate the true load on the machine. See Art. **44.**

(22) (*a*) Pilot lamps are used to indicate when a machine is "picking up" all right and also to give an approximate indication as to whether or not it is up to the proper voltage.

(*b*) Yes; because they must be connected so as to give an indication before the main switch is thrown in. See Arts. **44** and **45.**

(23) By cutting cells in or out by means of end-cell switches. See Art. **64.**

(24) The arrangement of this board is left as an exercise for the student. Many different arrangements are possible, but one similar to that shown in Figs. 58 and 59 would probably be as convenient as any. A sketch of connections similar to Fig. 59, showing the relative location of the different instruments and switches, is what is required.

(25) (*a*) Compensators are used to make the station voltmeter give indications of the voltage at the receiving end of the line and thus avoid the use of pressure wires. See Art. **17.**

(*b*) See Art. **19.**

ELECTRIC LIGHTING.

(PART 8.)

---

(1) See Art. **107.**

(2) Lightning, defective cut-outs, rocker-arm failing to move properly, lamp burning with an abnormally long arc. See Art. **83.**

(3) The magnet cores of the alternating-current lamp must be laminated, whereas in a direct-current lamp they may be solid. Also, in the alternating-current lamp a choke coil is used to take up the excess voltage, whereas in the direct-current lamp a resistance must be used. See Art. **64.**

(4) (*a*) About $\frac{1}{16}$ inch to $\frac{3}{32}$ inch.

(*b*) About $\frac{3}{64}$ inch. See Art. **82.**

(5) The lamp will overheat and the regulating coil may be burned out because the current will be larger than it should be. The resistance in series with the lamp will be overheated and the enclosing globe may be melted. See Art. **86.**

(6) (*a*) No. 6 or 8 B. & S. weather-proof line wire. No. 6 is generally used, as it does not cost much more than No. 8, has a lower resistance, and makes a stronger and more durable line.

(*b*) ecause it makes the location of faults much easier and quicker. See Arts. **87** and **89.**

(7) See Art. **66.**

(8) 6.6 amperes and 70 to 78 volts. See Art. **72.**

(9) See Arts. **41** and **42.**

(10) See Art. **39.**

(11) See Figs. 21 and 22.

(12) (*a*) Because if the ca ns should stick or fail to feed, the arc would gradually w longer and there would be danger of the shunt coils b burned out. Also, there would be danger of the circui ing broken. See Art. **49.**

(*b*) In order to provide a fficient drop of potential through the lamp so that suffic t current will pass through the series coils to enable the lar to start up. See Art. **49.**

(13) See Arts. **53** and **54.**

(14) (*a*) By varying the amount of resistance in series with the arc. See Art. **76.**

(*b*) By cutting in or out some of the sections of the choke coil. See Art. **78.**

(15) (*a*) The series system, because it allows the use of a small current at high pressure, thus supplying the scattered lights with but small loss in power.

(*b*) By means of a switch that short-circuits the terminals of the lamp.

(*c*) The voltage must increase as the load, i. e., the number of lamps, is increased.

(*d*) No; the current must remain constant. It is maintained at a constant value by means of an automatic regulator on the dynamo. See Arts. **30** and **31.**

(16) See Arts. **32** and **33.**

(17) (*a*) 450 watts.
(*b*) 300 watts. See Art. **25.**

(18) (*a*) Petroleum-coke or gas-retort carbon.

(*b*) Because the impurities, if present in any considerable quantity, are deposited on the inner globe and obscure the light.

(*c*) Lampblack. See Arts. **16** and **17.**

(19) (*a*) See Figs. 7 to 11, inclusive.

(*b*) See Art. **15.**

(20) (*a*) Because the crater is formed in the positive carbon, and if the upper carbon is not made positive, most of the light will be thrown upwards instead of downwards.

(*b*) By noting which carbon remains hot for the longer time when the current is turned off. The upper or positive carbon should be the hotter. See Art. **14.**

(21) No; the ends of the carbons are nearly flat, due largely to the shifting of the arc over the ends. See Art. **12.**

(22) About 6.6 amperes for lamps giving 1,200 nominal candlepower, and 9.6 amperes for lamps of 2,000 nominal candlepower. See Art. **7.**

(23) (*a*) One in which the arc is surrounded by an enclosing globe that, to a large extent, excludes the air from the arc.

(*b*) The consumption of carbon is very much less. An enclosed-arc lamp can easily burn from 100 to 150 hours without retrimming, whereas an open arc can burn about 10 hours only.

(*c*) See Art. **8.**

(24) The carbon points become heated to a very high degree and become pointed. The positive carbon becomes hotter than the negative and burns away about twice as fast. The positive carbon has a crater formed in the end and the greater part of the light is emitted from this crater. See Arts. **3** and **4.**

ELECTRIC LIGHTING.

(PART 4.)

(1) To operate circuit *1'* on machine *A*, insert plugs at $b_{10}-c_{10}-b_6-c_6-b_2-c_2$. To operate circuits *2'* and *3'* in series on machine *C*, insert plugs at $f_{10}-f_9-d_9-d_6-d_2-e_2-e_3-f_3-f_2-g_2-g_6-g_{10}$.

(2) A diagram similar to Fig. 6 is required.

(3) By disconnecting the ends of the faulty coil from the commutator, tying them back out of the way, and connecting the segments by means of a "jumper." See Art. **37.**

(4) (*a*) Those with open-coil armatures and those with closed-coil armatures.

(*b*) The Brush and Thomson-Houston machines belong to the first class, and the Wood or Fort Wayne, Western Electric, Excelsior, and Ball belong to the second. See Art. **15.**

(5) See Art. **69.**

(6) By connecting one side of the voltmeter to the line and the other to the ground, as indicated in Fig. 3. See Art. **4**.

(7) See Arts. **25** and **26.**

(8) The new machine is of the multipolar type and is of considerably larger capacity than the old style. It requires no wall controller, but is provided with a controller on the machine itself. See Arts. **22** and **23.**

(9) See that the current always flows through the circuits in the proper direction. Never open a circuit when the current is on. If the circuit must be cut out, first short-circuit its terminals. See Arts. **53** and **55.**

(10) In order to keep the current at a constant value. Arc machines are series-wound, and if no regulator were provided, the current would increase as lamps were cut out and decrease as they were cut in. See Art. **14.**

(11) Plug from *A*+ to *1*+, and from *A*− to *1*−. Plug *B*+ to *3*+, *3*− to *4*+ by means of cable *J*, and *4*− to *B*−.

(12) Constant potential, because the same alternators can then be used for both arc and incandescent lighting. See Arts. **13** and **42.**

(13) The flashing occurs at regular intervals. See Art. **20.**

(14) See Art. **47.**

(15) $\frac{3}{16}$ to $\frac{1}{4}$ inch. See Art. **20.**

(16) They may be operated directly from the alternator by providing each lamp with a choke coil that is cut into circuit in case the lamp goes out. They may also be operated by using a transformer with an adjustable secondary, by using a constant-current transformer, or by inserting a reactance in the circuit, this reactance being arranged so that it varies with changes in the load in such a way as to keep the current constant. See Arts. **43** to **50.**

(17) Improper setting of brushes, defective air blast, overload on machine, speed too low, cross on line, break in shunt circuit of lamps. See Art. **20.**

(18) The break is located by first grounding both ends of the circuit at the station. The circuit is then opened about its middle point and each side rung up, in turn, by connecting one terminal of the line to the magneto and the other to the ground. After determining which side the break is in, the circuit is completed at this point and the lineman moves on to another point about half way between

the station and the last point tested. In this way the stretch of circuit in which the break is known to exist is narrowed down to within small limits. See Art. **2.**

(19) See Art. **40.**

(20) Inaccurate setting of brushes, defects in air jets, dirty commutator, too much oil on commutator, too large current, ragged or bent brushes. See Art. **21.**

(21) See Art. **39.**

(22) To improve the regulation when the machine is operated on a number of lamps considerably less than its normal capacity. See Art. **16.**

(23) The circuit ends are left open at the station, and the different parts of the line are rung up for grounds, by opening the circuit and connecting one terminal of the magneto to the line and the other to the ground. See Art. **3.**

(24) Because the coil will overheat on account of the local currents set up in it, and this overheating might injure the adjacent coils. See Art. **37.**

INTERIOR WIRING.

(PART 1.)

(1) If the drop is excessive, the lamps will not burn with uniform brilliancy, because the lamps near the source of supply get a higher voltage than those far removed, and those lamps on which the voltage is low would give an unsatisfactory light. See Art. **77.**

(2) (*a*) Slow-burning weather-proof wire is allowable for open work in dry places, such as mill wiring, etc.

(*b*) It must be supported clear of all woodwork by means of porcelain, glass, or other non-combustible, non-absorptive insulators. See Art. **59.**

(3) A fuse block or circuit-breaker must be placed as near as possible to the point where the service wires enter the building. Fuse blocks must be placed wherever there is a change in the size of the wire, unless the fuse in the cut-out protecting the larger wire will protect the smaller wire also. See Art. **51.**

(4) (*a*) If lamps are burned after they become dim, they give out very little light compared with the power that they consume; i. e., the watts per candlepower become very high, and it therefore pays better to put in new lamps. See Art. **14.**

(*b*) The effect of burning a lamp above its rated voltage is to increase the candlepower, but at the expense of greatly shortening the life of the lamp. See Art. **14.**

(5) Calculate the wiring as if it were for 220 volts. This will give the size of the outside wires. Make the middle wire of such size that it can safely carry the current required by one side of the system. See Art. **86.**

(6) If there are 120 lamps, there will be 40 lamps on each branch, or $\frac{40}{2} = 20$ amperes. Hence, from formula **1,**

$$C_m = 20 \times 1.73 = 34.6 \text{ amperes. Ans.}$$

Here C_m is the current in each of the main wires. See Art. **44.**

(7) (*a*) From 3.1 to 5 watts per candle. See Art. **15.**

(*b*) Total watts $= 32 \times 4 = 128$. Voltage $= 110$.

Hence, Current $= \frac{128}{110} = 1.16$. Ans.

(8) (*a*) Cut-outs are used to prevent wires being overloaded. They open the circuit whenever the current exceeds the allowable amount and thus prevent the wires from being overheated and burned out.

(*b*) They usually take the form of a piece of soft, fusible wire, which melts and opens the circuit whenever the current becomes excessive. These fuses are provided with metal terminals that are attached to corresponding terminals mounted on a slate or porcelain base. In many cases the fuse is enclosed in order to protect it from air-currents and to keep it from coming in contact with other substances. See Art. **50.**

(9) There will be 250 lamps on each side of the two-phase system; hence, the current in each line will be $250 \times \frac{1}{2} = 125$ amperes. See Art. **45.**

(10) See rule *c*, Art. **26.**

(11) The open arc burns exposed to the atmosphere, whereas the enclosed arc is confined in a small globe from which the oxygen is practically all burned out. The result is that the carbon burns very slowly, and such lamps will burn 100 to 150 hours without being retrimmed. The

enclosed arc is longer than the open arc and requires a higher voltage. See Arts. **20** to **23,** inclusive.

(12) (*a*) The total current is 250 amperes, allowing $\frac{1}{2}$ ampere per lamp. Resistance $= \frac{E}{C} = \frac{5}{250} = .02$ ohm. Total length of line wire is $400 \times 2 = 800$ feet, or .8 thousand feet. The resistance per 1,000 feet must, therefore, be $\frac{.02}{.8} = .025$ ohm. A No. 0000 wire has a resistance of .049 ohm per 1,000 feet, as may be seen by consulting Table V, so that two No. 0000 wires in multiple will have a resistance of .0245 ohm per 1,000 feet and will answer in this case. See Art. **81.**

(*b*) If carrying capacity alone were considered, No. 000 weather-proof wire would answer, because the Underwriters allow 262 amperes for this size of wire.

(13) The carrying capacity of rubber-covered wire is lower than that of weather-proof wire, because the rubber covering is subject to gradual deterioration under the action of heat. See Art. **30.**

(14) Because a resistance must be used in series with these lamps, and a portion of this resistance may just as well be in the branch wires connecting the lamp with the mains. Of course, no wire smaller than No. 14 should be used. See Art. **24.**

(15) (*a*) See Art. **80.**

(*b*) A mil is equal to $\frac{1}{1000}$ inch.

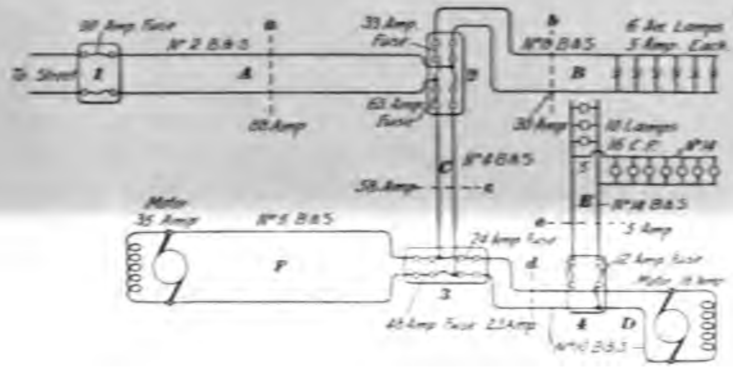
(16) The amount of energy supplied to any one circuit dependent on one cut-out is limited to 660 watts by rule *d*, Art. **51**; hence, the number of lamps allowable is easily determined. About 10 16-candlepower lamps per circuit is usually taken as the limit.

(17) See Art. **3.**

(18) The illustration shows the wiring provided with the necessary cut-outs and with the currents indicated in the various parts.

(*a*) Current at *a*, 88 amperes; *b*, 30 amperes; *c*, 58 amperes; *d*, 23 amperes; *e*, 5 amperes.

(*b*) The sizes of wire will be No. 2 for section *A*, No. for *B*, No. 4 for *C*, No. 10 for *D*, No. 14 for *E*, No. 6 for *F*. See Underwriters' Table, Art. **30.** In each case the wir has been taken that is on the large side, so that the carryin capacity will be ample. If the distances were short, it is probable that so many different sizes would not be used. Fo example, sections *C* and *F* might both be No. 4, althoug No. 4 is not absolutely necessary for section *F*. If, however, the distances were long, it would pay to use the different sizes, as indicated.



(*c*) The actual arrangement of cut-outs may vary considerably. A cut-out must be placed at each point where there is a change in the size of the wire, and a main cut-out should, therefore, be placed at 1, and [illegible]-ampere fuses would be the greatest allowable size to use in it. At 2 we may place a single branch block for *C* and a main block for *B*, or we may use two single branch blocks or one double branch block. In the figure, a double branch block 2 is shown, the side connecting to *B* being fused with fuses not larger than [illegible] amperes capacity, and the side connecting to [illegible] with fuses not exceeding [illegible] amperes capacity. At 3 a double branch block may also be used, one side being fused for 24 amperes capacity and the other for 46 amperes capacity, as indicated. To supply branch *E*, a single branch block *4* will be required, and its fuse must not be over 12 amperes capacity. No branch block will be required at *5*, because the size of wire is not changed there. The current capacity of the fuses indicated in the figure is the same as the current capacity of the wires that they protect. In practice, however, fuses of standard size would be used, and these might not always be of the same capacity of the wire. In any event, the rated capacity of the fuse should not exceed the allowable carrying capacity of the wire it protects.

J. B. Brilhart.

(19) Safety, satisfactory operation, convenience and neatness, economy. See Art. **2.**

(20) The effect is to greatly increase the drop, because the low-voltage lamps require a larger current than the high-voltage ones and the line resistance is the same in both cases. The low voltage, of course, results in unsatisfactory service, to say nothing of the danger of overloading the wiring that is introduced by the change. See Art. **84.**

(21) See rule *c*, Art. **53.**

(22) (*a*) No. 14 B. & S. See rule *a*, Art. **26.**

(*b*) The current-carrying capacity as given by the Underwriters.

(23) The wiring may be divided into distribution circuits and mains. The former run to the lamps from the distributing centers and the latter connect the outside lines to the distributing centers. See Art. **48.**

(24) (*a*) It effects a considerable saving in the amount of wire required to transmit the current, because it admits the use of a higher voltage than the two-wire system.

(*b*) If one side of the system is loaded much heavier than the other, the voltage becomes unbalanced, and the devices connected to the lightly loaded side have a higher voltage thrown on than they are intended for. The wiring is also

INTERIOR WIRING.

(PART 2.)

(1) A line 120 feet long having a drop of 3 volts would be the same size as a line $\frac{120}{3} = 40$ feet long having a drop of 1 volt. In Table I, under 40 and on the same horizontal line with 30, we find No. 6 as the size wire required.

(2) $\frac{1}{8}$ inch $= 125$ mils. $125 \times 125 = 15{,}625$ circular mils. See Art. **6.**

(3) Tests should be made to see if all connections are correct, and also to detect any grounds or crosses between wires. All circuits should be tested before fixtures of any kind are put up, and each fixture should be tested after it is wired, but before it is put in place. See Art. **71.**

(4) (*a*) See Art. **73.**

(*b*) Before the building is lathed and plastered.

(5) A magneto-bell, commonly called a magneto, that is capable of ringing its own bell through a resistance of at least 5,000 ohms is generally used.

(6) The total current $= 80 \times \frac{1}{2} = 40$ amperes. By formula **1** the resistance per 1,000 feet r_m of the proper size wire to use equals $\frac{2 \times 1{,}000}{2 \times 200 \times 40} = .125$ ohm per 1,000 feet. This would require a No. 1 wire, which has a resistance of .124 ohm per 1,000 feet.

) Dia. eter in mils = $\sqrt{10,816}$ = 104 mils = .104 in. S Ar

(8) oltage across the outside wires at the lamps = 220 − 4 = 6 volts. Substituting in formula **7,** we have

$$\text{Current} = \frac{60 \times 52}{216} = 14.4 \text{ amperes. Ans.}$$

(9) As in Art. **12,** divide the current by the drop, which gives $\frac{30}{3} = 10$. Now follow down in the column under 10 amperes until the nearest distance to 120 feet is obtained. This will be found to be l to the left of this in the first column will be found e of wire required, namely, No. 6 B. & S.

(10) The 50 lan 25 amperes. Substituting the values given , we have circular mils $= \frac{21.6 \times 25 \times}{2}$ tween a No. 4 and No. 5 B. & S. N as 1.

(11) The e ce of the line should be $\frac{2}{40}$ = .05 ohm. Since this line is 200 feet long, counting both ways, then the resistance per 1,000 feet must be $\frac{.05}{200} \times 1{,}000$ = .25 ohm. The resistance of a No. 6 wire per 1,000 feet = .394 ohm. Let r_1 = .394 ohm and r_2 = the resistance per 1,000 feet of the wire required. Then, by substituting in the formula $\frac{1}{R} = \frac{1}{r_1} + \frac{1}{r_2}$, we have $\frac{1}{.25} = \frac{1}{.394} + \frac{1}{r_2}$, or $\frac{1}{r_2} = \frac{1}{.25} - \frac{1}{.394} = \frac{.394 - .25}{.25 \times .394}$; hence, $r_2 = \frac{.25 \times .394}{.144} = .684$. A No. 8 B. & S. gauge wire, resistance .6271 ohm per 1,000 feet, most nearly meets this requirement. See Art. **17.**

(12) (*a*) See Art. **18.**

(*b*) See Art. **19.**

(13) (*a*) Wooden molding may be used in finished houses on ceilings and walls, and in show windows for temporary purposes, where it is desirable to hide the wire and give the work a neat appearance.

(*b*) It must not be used in concealed work nor in any damp places or where the difference of potential is over 300 volts. See Art. **69.**

(14) The constant motion and vibration of the ship, which tend to chafe and break the wires; also the constant presence of dampness. See Art. **76.**

(15) (*a*) A main switch and cut-out.

(*b*) The cut-out should be placed nearest the point where the wires enter, then the switch, and finally the meter. See Art. **34.**

(16) By means of two three-point switches, one at each point from which it is desired to control the lamps. Make a sketch similar to (*a*) or (*b*), Fig. 18. See Art. **37.**

(17) So that if a wire comes in contact with any section of a conduit or fitting, there will be afforded a direct path to ground through which current may escape to earth. This prevents the current leaking to ground through any other paths and thereby reduces the likelihood of a fire. See Arts. **62** and **63.**

(18) (*a*) Because it is not waterproof and is, therefore, not suitable for use in damp places.

(*b*) Lined and unlined iron pipe.

(19) The loop system is one in which the same pair of wires passes in series through all outlets at which lamps to be connected on that one circuit are located; that is, no branch circuits are tapped on except at outlet or junction boxes. See Art. **57.**

(20) The smaller wire must be protected by a cut-out. See Art. **59.**

(21) The wires must be brought out, for combination fixtures, through insulating tubes or an approved outlet insulator in such a manner that they cannot touch gas pipes, metal work, or plaster. At outlets where there are no gas pipes, ordinary porcelain tubes may be used. See Art. **22** and rule *c*, Art. **23.**

(22) They must be rigidly supported on non-combustible, n-absorptive insulators that keep the wires at least 1 inch om the surface wired over, and should be kept at least 0 inches apart and run on separate timbers or studding henever possible. In some cases, especially where a large umber of wires come together near the junction or panel boards, it is impossible to observe this rule absolutely, and the inspectors will usually pass work in such cases that does not fully meet the requirements, provided wires are kept at least $2\frac{1}{2}$ inches apart or are run in an armored cable or conduit. See Art. **23.**

(23) (*a*) Since the two wires have a greater surface area than the one wire of equivalent cross-section, they can radiate the heat faster and hence can safely carry more current.

(*b*) Since the resistance of the two wires in parallel is equal to that of the one larger wire of equivalent cross-section, then the drop, which is equal to $C \times R$, will be the same in both. See Art. **16.**

(24) The resistance of the line (both ways) $= \frac{3}{50 \times \frac{1}{2}}$ $= .12$ ohm. Total length of line $= 2 \times 100 = 200$ feet. The resistance of 1,000 feet of No. 14 = 2.521 ohms; hence, the resistance of 200 feet $= \frac{2.521 \times 200}{1,000} = .5042$ ohm. All the wires in multiple are to be No. 14, then each wire will have a resistance of .5042 ohm, and the combined resistance must equal .12 ohm. Hence, if x = the number of No. 14 wires in multiple and R the combined resistance = .12 ohm, then we have $\frac{.5042}{x} = .12$, or, from the formula given in Art. **17.** $\frac{1}{.12} = \frac{x}{.5042}$, from either of which $x = 4.20$. Hence, four No. 14 wires in parallel would be required for each side of the circuit.

(25) (*a*) Waterproof sockets should be used.

(*b*) They should be connected and hung by separate rubber-covered stranded conductors, not smaller than No. 14 B. & S. The two conductors should preferably be twisted together when their length is over 3 feet. They should be soldered directly to the circuit wires, but supported so that the weight of the lamp socket and wires will not be borne by the circuit wires. Rosettes should not be used. See Art. **18.**

(26) (*a*) A single-pole switch may be used where it does not control over 660 watts.

(*b*) Because they cost less and the necessary wiring is cheaper. See Art. **36.**

(27) Because not more than 660 watts are allowed on one circuit by the Underwriters and No. 14 is plenty large enough to safely carry the current; moreover, the distances are usually so small that the drop is never too large on 110-volt or higher pressure systems, even with the maximum allowable number of lamps on the branch circuits. No. 14 wire being the smallest size allowed by the Underwriters is therefore used for most branch circuits. See Art. **32.**

INTERIOR WIRING.

(PART 3.)

(1) It is important to burn the lamps at a proper and uniform voltage, but the drop or efficiency is a secondary matter; hence, a large drop may be allowed and comparatively small wires may be used, but lamps of the proper voltage should be used even if this requires lamps of different voltages in the various parts of the circuit or system. See Art. **10.**

(2) See Art. **16.**

(3) It depends on the ratio of the number of turns in the primary and secondary coils of the transformer. See Art. **18.**

(4) Because a protective device for use on a constant-potential circuit is made to open the circuit in order to protect it, but on a constant-current system, it must *short-circuit* and *not open* the circuit. See Art. **23.**

(5) See Art. **23.**

(6) (*a*) A self-restoring annunciator is so constructed that when a button is pushed, its corresponding drop falls. The next call operates a magnet that moves a restoring device, which in turn resets the first drop.

(*b*) It obviates the necessity of restoring the drops by hand. Moreover, with hand-restored annunciators, there may be one or more drops down, due to their not having been promptly restored, and hence if another drop falls, t may be difficult to tell which drop fell last and which one needs to be answered. See Art. **41.**

(7) Direct-current series-arc lighting systems. See Art. **17.**

(8) Since one side of the system is grounded, it is very easy for the current to start leaking to earth, and hence the fire risk is great, to say nothing of the risk from shocks. See Art. **29.**

(9) The wires must be rubber-covered and must be kept at least 8 inches apart. See Art. **24.**

(10) (*a*) A motor and starting resistance box must be protected by a cut-out and controlled by a switch that shows plainly whether it is on or off.

(*b*) Single-pole switches may be used with motors of ¼ horsepower or less and then only on low-tension circuits. See Art. **28.**

(11) It is dangerous to life and, moreover, a lightning discharge can easily start an arc, and an arc once started will persist even though the points between which it plays are separated several inches; hence, it is liable to start a fire. See Art. **17.**

(12) It should be surrounded by a wood platform supported on insulators and extended around the machine so that a man must stand upon the platform before he can touch any part of the machine.

(13) (*a*) Resistance boxes and reactive, or choke, coils.

(*b*) Resistance boxes may be used on direct- or alternating-current systems, but reactive, or choke, coils, although the more economical of the two, can only be used on alternating-current systems. See Art. **9.**

(14) No. See Art. **66.**

(15) See Art. **20.**

(16) It is best to use rubber-covered wire in very moist or wet places for bell and annunciator wiring. See Art. **42.**

(17) Their use is recommended and they must be used when required. See Art. **28.**

(18) Without special permission transformers must not be placed inside a building, except in central stations, and if a transformer is fastened to an outside wall, it must be separated from the wall by substantial supports. See Art. **19.**

(19) (*a*) The most common form of theater dimmer consists of a resistance split up into a number of sections, so that the amount of resistance between the terminals of the dimmer may be varied by the movement of a handle that controls a contact device.

(*b*) In series with the circuit, so that the total resistance, and hence the total current and intensity of illumination, may be varied as desired by manipulating the handle. See Art. **9.**

(20) Two wires should never be fastened under one unprotected or uninsulated metal staple and a staple should never be driven in so hard as to cut through or injure the insulation of the wire. See Art. **42.**

(21) See Art. **26.**

(22) Because all the air gaps at the burners in one circuit are in series, and hence offer a great resistance to the sparking current; and since a current will take the easiest path to ground, it follows that the current will jump to ground instead of across all the spark gaps if there is a point where the resistance to ground is less than the resistance of all the spark gaps. Consequently, it is very necessary to highly insulate the circuit on a series gas-lighting system in order to make the system work properly. See Art. **68.**

(23) Care must be taken to use a wire large enough to carry the current. The current required by the motor may usually be determined from the name plate, but if not given, the table, Art. **26,** may be used. Also, the motor must be equipped with a suitable starting box that complies with the Underwriters' requirements. See Art. **27.**

INDEX.

NOTE.—All items in this index refer first to the section (see the Preface) and then the page of the section. Thus, "Annunciators 28 29" means that annunciators will e found on page 29 of section 28.

A. *Sec.* *Page.*

djustments for arc lamps ... 18 73
lternating-current ammeters and voltmeters. 17 12
" current arc-light dynamo.... .... 19 35
" current constant-current system.. 16 60
" current constant-potential enclosed-arc lamp. 18 69
" current constant-potential system 16 50
" current dynamos for incandescent lighting 16 87
" current lightning arresters 17 47
" current switchboard 17 58
" current switchboards for parallel running...... 17 61
" current, Wiring calculations for.. 27 8
mmeters and voltmeters...... 17 9
" and voltmeters, Alternating-current. 17 12
" and voltmeters, Weston............ 17 9
" on arc switchboards 19 55
nnunciator, Needle........... 28 30
" Self-restoring.... 28 31
nnunciators 28 29
pparatus for multiple-lighting system....... .... 28 49

Sec. *Page.*

Approved conduit systems . .. 27 50
Arc circuits, Laying out of..... 18 77
" circuits, Lightning protection for.................... 19 7
" dynamo, Brush 19 18
" dynamo, Wood............. 19 25
" lamp, Brush................ 18 44
" lamp lightning arrester.... 19 9
" lamp, Photometry of 18 15
" lamp pulleys............... 18 84
" lamp, Thomson-Houston.. 18 49
" lamp, Wood................ 18 53
" lamps....................... 26 16
" lamps, Candlepower of.... 18 21
" lamps, Constant-current... 28 15
" lamps, Cut-out switches for 18 85
" lamps, Examples of........ 18 42
" lamps, Constant-potential....................... 18 37
" lamps for constant potential....................... 18 66
" lamps in multiple series... 18 35
" lamps, Methods of distribution for.. .... 18 26
" lamps, Methods of hanging....................... 18 80
" lamps, Parallel distribution for.................. 18 31
" lamps, Power consumption of.................. .. 18 24
" lamps, Rope for............ 18 84
" lamps, Series distribution for.................. 18 26
" lamps, Space illuminated by....................... 18 25

Sec. Page.

Arc lamps, Special applications of........ 18 89
" lamps, Wiring for.......... 28 14
" light carbons.............. 18 11
" light dynamo, Alternating current of.......... 19 35
" light dynamo, Thomson-Houston................ 19 12
" light lines, Differential method of locating grounds on.............. 19 5
" light lines, Locating breaks on............... 19 2
" light lines, Locating grounds on............. 19 3
" light lines, Locating grounds on, by means of voltmeter............. 19 4
" light lines, Testing of...... 19 1
" light switchboards......... 19 44
" lighting, Constant-current transformers for........ 19 38
" lighting, Size of wire for.. 18 77
" lighting, Station equipment for................. 19 10
" machines, Care of.......... 19 28
" machines, Insulation of.... 19 28
" machines, Multicircuit.... 18 28
" machines, Reversal of polarity of................. 19 33
" machines, Running in series of................. 19 34
" machines, Troubles in armatures of............... 19 31
" machines, Troubles in field coils of.................... 19 32
" switchboard, Panel type of 19 51
" switchboard, Voltmeter for 19 55
" switchboards, Ammeters for........................ 19 55
" switchboards, Construction and operation of.... 19 46
" switchboards, Wattmeter for........................ 19 56
" switchboards without cables.................... 19 48
" Temperature of............ 18 4
" Voltage of................ 18 4
Arcs, Open...................... 18 1
Armatures for Thomson-Houston dynamo............ 19 13
Armored cable.................. 27 24
Arrangement of carbons........ 18 11
" of lighting apparatus....... 28 15
Automatic burner.............. 28 44

Sec. Page.

Automatic cut-outs, Rules relating to........... 26 35
" drop.................. 28 38

B. Sec. Page.

Bare copper wire, Dimensions of........................... 26 24
Bases for incandescent lamps.. 16 10
Batteries...................... 28 27
" Regulation of......... 17 73
Battery equipment for lighting plants......................... 17 72
Bell and annunciator circuits.. 28 32
" wire, Method of running.. 28 31
" wiring.................. 28 24
Boosters, Use of............... 16 48
Brush arc dynamo.............. 19 18
" arc dynamo, Connections for............... 19 25
" arc dynamo, Regulator for..................... 19 20
" arc lamp................ 18 44
" plug and spring jack.... 19 52
Bunsen photometer............ 16 18
Burglar alarm.................. 28 40
Burned-out arc-lamp coils...... 18 74
Bus-bars........................ 17 7
Buzzer.......................... 28 25

C. Sec. Page.

C. R. regulator................. 16 63
Cabinets and panel boards, Use of............................ 27 25
Calculation of line losses due to resistance.... 26 59
" of proper size of wire for a given loss.............. 26 62
" of wire in terms of circular mils.... 27 5
" of wire sizes in terms of resistance per 1,000 feet 27 3
Candlepower, Mean horizontal 16 22
" Mean spherical.. 16 24
" of arc lamps.... 18 21
Canopy insulator.............. 27 45
Carrying capacity of insulated wires........................ 26 22
Capacity of wires for marine work.......................... 27 70
Carbon-cylinder cells.......... 28 29
Carbons, Arrangement of 18 11
" Composition of........ 18 14
" for arc lights......... 18 11

Sec. *Page.*
Care and adjustment of arc lamps.................. 18 72
" of arc machines.......... 19 28
Center of distribution.. . .... 26 33
" of distribution.......... 26 64
" of distribution.......... 16 70
Character of enclosed arcs..... 18 9
Circuit-breakers................ 17 27
" breakers.... . ... 26 34
Circuits, Laying out of......... 27 31
Combining several wiring systems........................... 28 1
Compensating voltmeters...... 17 19
Compensation for heating in arc lamp 18 62
Compensator, Mershon......... 17 21
Composition of carbons........ 18 14
Concealed electric-light wiring, Specifications for......... 27 37
" knob-and-tube work........ .. 27 21
Conductors in multiple, Fuse protection of....... .... 27 14
Conduit, Flexible armored..... 27 61
" systems, Approved... 27 50
" systems, Early........ 27 49
" wire and installation, Underwriters' rules relating to.... 27 58
" wiring 27 49
Conduits, Drawing wires in. .. 27 62
Connections for testing incandescent lamps................. 16 26
Constant-current arc lamps.... 28 15
" current arc-light dynamo................. 19 11
" current series arc lamp, enclosed arc.. 18 55
" current series lamps, open arc 18 42
" current transformers for arc lighting...... 19 38
" direct current, Series enclosed-arc lamps for........... .... 18 58
" potential arc lamps... 18 37
" potential arc lamps... 18 66
Construction and operation of arc switchboards......... 19 46
" of enclosed-arc lamp.......... 18 57
" of lamps. 16 1
Control of lamps from two points 27 39
Control of lights from three or more points..................... 27 41
Crowfoot battery............... 28 42
Current allowance for incandescent lamps. .. 16 77
" required by lamps, Estimation of 27 7
" required by motors... 28 20
" transformers.......... 17 14
Cut-out switches for arc lamps 18 85
" out cabinets, Rules relating to 27 20
" outs, Location of........... 26 44

D. *Sec.* *Page.*
Damp places, Wiring in........ 27 18
Decorative series lamps........ 27 46
Definition of low-potential system. 26 24
Determination of sizes of wire according to current capacity 26 44
Differential method of locating grounds on arc-light lines.... 19 5
Dimensions of bare copper wire.......................... 23 24
Direct-connected alternators... 13 62
" current constant-current system....... .. .. 16 50
" current constant potential enclosed-arc lamp. 18 67
" current constant-potential system............ 16 43
" current switchboards... 17 52
Distribution, Center of......... 16 70
" circuits........... 26 33
Door openers....... .... 28 39
Drawing wires in conduits..... 27 62
Drop, Measurement of, in volts 27 67
Dwelling house, Wiring of. .. 27 30
Dynamos for incandescent lighting........................ 16 81

E. *Sec.* *Page.*
Early conduit systems.......... 27 49
Economy of space in conduit systems...................... .. 27 61
Edison plug cut-outs..... ...... 26 52
" three-wire system 26 27
Efficiency of incandescent lamps...... .... 16 26
" of transformers..... 16 75
Electric bell...................... 28 21
" gas lighting............ 28 43
" gas lighting, Frictional machines for........ 28 50

Sec. Page.

Methods of distribution for arc lamps.......... 18 26
" of hanging arc lamps. 18 80
Methven screen.......... 16 13
Mirrors fór searchlights.......... 18 92
Mixed systems.......... 16 54
Monocyclic system.... ..... 26 33
Motors, Current required by... 28 20
Multicircuit series-arc machines.......... 18 28
Multiple-lighting system, Apparatus for.......... 28 49

N. *Sec. Page.*

National electrical code.......... 26 2
Needle annunciator.......... 28 30
Nernst lamp.......... 16 35

O. *Sec. Page.*

One bell operated from two points.......... 28 33
Open-arc lamps.......... 26 16
" arc, series-arc lamps..... 18 39
" arcs.......... 18 1
" arcs, General features of 18 1
" work in dry places....... 26 40
Operating bell from lighting circuit.......... 28 29
Operation of incandescent lamps..... .. .. 26 14
" of series arc lamps from constant-potential alternators 19 37
Outlet and junction boxes, Use of.......... 27 53

P. *Sec. Page.*

Panel type of arc switchboard. 19 51
Parallel distribution for arc lamps.......... 18 31
Photometer bar.......... 16 19
" Bunsen.......... 16 18
" Elementary.......... 16 16
" Law of.......... 16 14
Photometry of the arc lamp.... 18 15
Plug and spring jack, Brush... 19 52
" and spring jack, Western Electric.......... 19 54
Porcelain fuse blocks...... .... 26 52
Portable conductors.......... 27 70
Potential regulators.......... 17 64
" transformers...... .. 17 14
Power consumption of arc lamps.......... 18 24

Sec. Page.

Power consumption for incandescent lamp.......... 26 15
Pressure wires.......... 17 18
Properties of incandescent lamps.......... 16 25
Pulleys for arc lamps.......... 18 84
Pure copper wire, Resistance of.......... 26 58
Push button.......... 28 36

R. *Sec. Page.*

Ratchet burner.......... 28 44
Reactive coils.......... 28 5
Regulation of arc lamps by means of variable reactance.......... 19 42
" of batteries.......... 17 73
Regulator, C. R.......... 16 63
" for Brush arc dynamo.......... 19 20
" Lamp-board.......... 16 63
" Stillwell.......... 17 65
Resistance of pure copper wire 26 58
Return-coil annunciator, Wiring for.......... 28 36
Reversal of polarity of arc machines.......... 19 33
Rheostats.......... 17 30
Rope for arc lamps.......... 18 84
Rubber-covered wire.......... 27 20
Rules relating to transformer construction and installation...... .... 28 13
" relating to wires. 26 21
" relating to wires for open work.......... 26 42
Running alternators separately 17 63
" arc machines in series 19 34
" bell wire..... .. .. 28 31

S. *Sec. Page.*

Searchlight lamp.......... 18 92
Searchlights.......... 18 91
" Care and operation of.......... 18 95
Selection of fittings for 220-volt wiring.......... 26 66
Self-restoring annunciator..... 28 31
Separate running of alternators.......... 17 63
Series-arc lamps, open arc..... 18 39
" arc lamps, Operation of, from constant-potential alternators.......... 19 37
" distribution for arc lamps.......... 18 26

	Sec.	*Page.*
Series-enclosed-arc lamps for constant direct current	18	58
" enclosed-arclamps, Voltage required by	18	56
Simple annunciator, Wiring for	28	35
" bell circuit	28	32
" example of factory wiring	26	40
Single-phase generator panel	17	58
" phase system	16	51
Size of wire for three-wire system	26	68
Slow-burning weather-proof wire	26	42
Snap switches	27	42
" switches, Rules relating to	26	39
Sockets and receptacles for lamps	26	51
Soldering fluid	26	20
Space illuminated by arc lamps	18	25
Sparking of T. H. dynamo.	19	17
Special applications of arc lamps	18	89
" bell-wiring appliances.	28	38
" purposes, Wiring for.	28	6
" three-wire systems	16	45
Specifications for concealed electric-light wiring	27	37
" for interior conduits	27	51
Stage dimmers	28	5
Standard candle	16	18
Station equipment for arc lighting	19	10
Stillwell regulator	17	65
Storage batteries, Use of, in lighting plants	17	68
Store lighting	28	1
Switches	27	39
" and cut-outs	26	34
" and bus-bars	17	1
" and connections for voltmeters	17	17
" High-tension	17	3
" cut-outs, and circuit-breakers, Rules relating to	26	35
Switchboard panels	17	51
Switchboards	17	50
" for alternating current	17	58
Switchboards for direct current	17	52
" General construction of	17	50
System, Alternating-current constant-current	16	60
" Alternating-current constant-potential	16	50
" Direct-current constant-current	16	50
" Edison three-wire	26	27
" Monocyclic	26	33
" Single-phase	16	51
" Three-phase	16	54
" Three-phase	26	31
" Three-wire	16	44
" Two-phase	26	32
" Two-phase	16	54
" Two-wire	26	27
" Two-wire	16	42
Systems, Five-wire and seven-wire	16	49
" Mixed	16	54
" of distribution	16	41
" Multiphase.	26	34
" of distribution for interior wiring	26	27

T.	*Sec.*	*Page.*
Tables and curves for interior wiring	27	9
Temperature of incandescent lamps	16	25
" of the arc	18	4
T. H. dynamo, Flashing of	19	16
T. H. dynamo, Sparking of	19	17
Testing arc light lines	19	1
Tests for interior wiring	27	65
Theater wiring	28	4
Thomson-Houston arc lamp	18	49
" Houston arc-light dynamo	19	12
" Houston dynamo, Armatures for.	19	13
Thomson's lightning arrester for arc circuits	19	7
Three-phase system	26	31
" phase system	16	54
" wire system	26	27
" wire system	16	44
" wire system, Size of wire for	26	68
" wire system, Unbalancing of	26	68
Transfer boards	19	56
Transformers	28	12

	Sec.	*Page.*
Transformers, Efficiency of	16	75
Trimming arc lamps	18	72
" enclosed-arc lamps	18	75
Troubles in armatures of arc machines	19	31
" in field coils of arc machines	19	32
Two bells operated from one point	28	32
" phase system	16	54
" phase system	26	32
" point switch	28	39
" wire system	26	27
" wire system	16	42

U.

	Sec.	*Page.*
Unbalancing of three-wire system	26	68
Underground conductors	26	21
Underwriters' tests	27	66
Uniform drop in feeder lines	27	1
" drop, Wiring for	26	56
Use of boosters	16	48
" of frequency changers	16	58
" of cabinets and panel boards	27	25
" of outlet and junction boxes	27	53
" of storage batteries in lighting plants	17	68

V.

	Sec.	*Page.*
Vertical distribution	16	23
Voltage of the arc	18	4
" required by series enclosed-arc lamps	18	56
" regulation	16	47
Voltages of incandescent lamps	16	32
Voltmeter on arc switchboard	19	55
" switches and connections	17	17
Voltmeters, Electrostatic	17	15

W.

	Sec.	*Page.*
Wattmeters for arc switchboards	19	56
Western Electric plug and spring jack	19	54
Westinghouse constant current incandescent system	16	66
" lightning arrester	17	42
Weston ammeters and voltmeters	17	9
Wire gauges	26	23
" Rubber-covered	27	20
" Slow-burning weatherproof	26	42
Wires, Equivalent cross-section of	27	16
" for high-potential systems	28	11
" for open work, Rules relating to	26	42
" for use on constant-current series-arc systems	28	17
" Rules relating to	26	21
" used in marine work	27	68
Wiring a dwelling house	27	30
" calculations for alternating current	27	8
" estimates	27	72
" for arc lamps	28	14
" for electric heaters	28	15
" for electric motors	28	21
" for electric motors, Rules relating to	28	22
" for elevator annunciator	28	37
" for low-potential systems	26	24
" for return-call annunciator	28	36
" for simple annunciator	28	35
" for special purposes	28	6
" for three bells and three push buttons	28	35
" for uniform drop	26	56
" in damp places	27	18
" table giving distances for loss of 1 volt	27	4
" tables and curves	27	9
" 220-volt selection of fittings for	26	66
Wood arc dynamo	19	25
" arc lamp	18	53
Wooden moldings	27	63
" moldings, Rules relating to	27	63

THE NEW YORK PUBLIC LIBRARY
REFERENCE DEPARTMENT

This book is under no circumstances to be taken from the Building

Form [illegible]